Transitions from the physics of time to temporal metaphysics

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Abstract

Some philosophers have suggested that we can deduce the temporal metaphysics of our universe from our theories of physics. The special and general theories of relativity in particular have been taken to imply that past and future moments of time have the same status as the present moment of time. Philosophers who propose this view of reality, which can be described as the *static block universe* view, frequently take their opponents to be claiming that only the present moment of time exists and that past and future moments of time do not exist, the so-called *presentist* view.

Presentism however is only one type of *objectively distinguished present* theory of time. It is possible to argue for an objectively distinguished present theory in which past moments as well as the present moment are conceived of as existing. This is the *growing block universe* view. It is also possible to argue for a physically distinguished present theory in which moments of time are distinguished not in terms of their state of existence but in terms of their state of determinacy. This is the *growing determinacy* view. On such a view, all moments are conceived of as existing, but past moments are regarded as determinate, the present moment as becoming determinate, and future moments as indeterminate.

The arguments for the static block universe view on the basis of special and general relativity are examined initially. It is demonstrated that it is not possible to describe in objectively distinguished present terms some universes which are modelled on the basis of relativity alone. However, it is further demonstrated that if a universe conforms to thermodynamical and quantum mechanical laws as well as to relativity, then that universe can be described in objectively distinguished present terms as well as in static block universe terms.

These results are interpreted as evidence that our current theories of physics, taken together, do not conclusively indicate the temporal metaphysics of our universe.

Acknowledgments

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ὁ μεν γαρ
῾Ηρακλειτος, ὁς ἡμιν παρακελευεται ζητειν τουτο
ἀμοιβας τε ἀναγκαιας τιθεμενος ἐκ των ἐναντιων
ὁδον τε ἀνω κατω εἰπων και μεταβαλλον
ἀναπαυεται και καματος ἐστι τοις αὐτοις
μοχθειν και ἀρχεσθαι εἰκαζειν ἐδωκεν ἀμελη-
σας σαφη ἡμιν ποιησαι τον λογον, ὡς δεον ἰσως
παρ᾽αυτῳ ζητειν, ὡσπερ και αὐτος ζητησασ εὑρεν

(Πλοτινυς *᾽Ενvεαδ* IV viii I)

Heraclitus, who urges us to investigate this, positing "necessary changes" from opposite to opposite, and saying "way up and down" and "changing, it is at rest", and "weariness to toil at and be subjected to the same things", has left us guessing; since he has neglected to make clear to us what he is saying, perhaps we ought to seek by ourselves, as he himself sought and found.

(Plotinus *Ennead* IV viii 1, trans. by A.H. Armstrong)

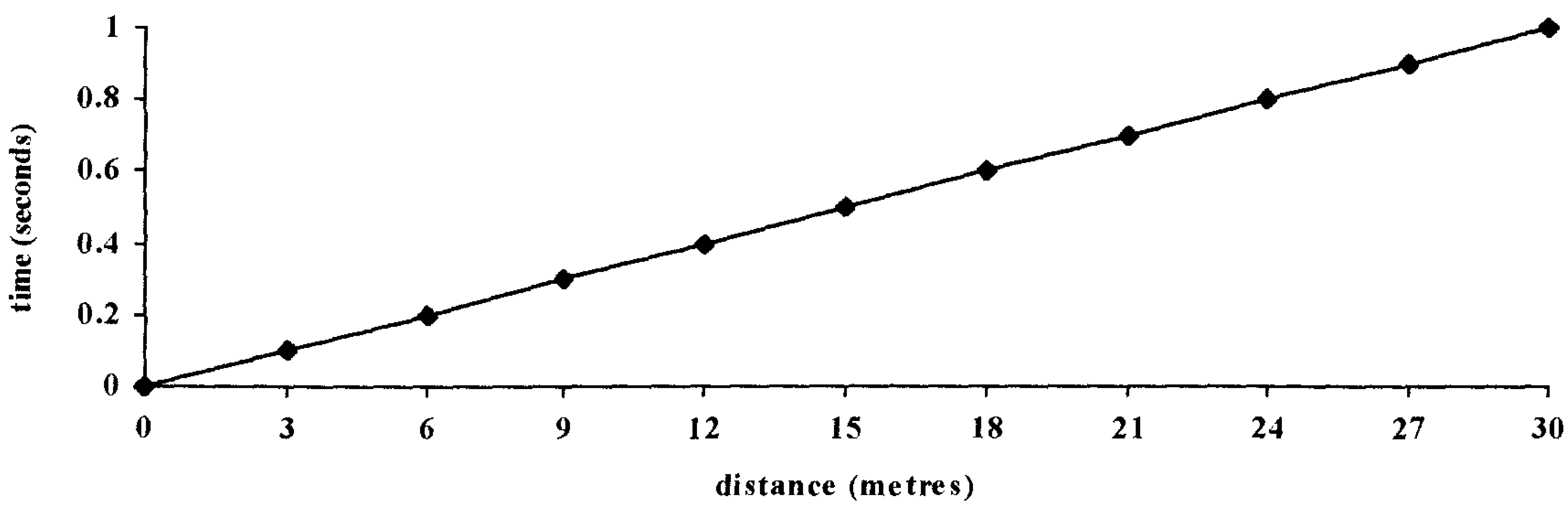
1

Theories Of Temporal Metaphysics

1 Locations In Space, Locations In Time

Imagine an archer firing an arrow from a bow towards a target thirty metres away. The arrow leaves the bow at a speed of thirty metres per second, and thus the length of time taken for the arrow to travel from the bow to the target, assuming that deceleration due to air resistance is negligible, is one second. Consider a plot of the distance of the arrow from the bow at intervals of one tenth of a second.

Fig. 1.1 Distance Travelled In One Second By An Arrow Travelling At 30m/s



At each moment of the arrow's flight, the arrow has a determinate location in space. After zero seconds, it is zero metres from the bow in the direction of flight, after one tenth of a second, it is three metres from the bow in the direction of flight, and so on. We think of each of these locations in space as existing, and can represent these locations on the x-axis of a graph as shown.

Now consider the *y*-axis of the graph. The *y*-axis represents locations not in space but in time.[1] Should I conceive of locations in time as existing in the same way as locations in space? My experience of time is different to my experience of space. I can perceive all the parts of a relatively short distance, such as the distance travelled by the arrow, in a single moment of time, but I never experience more than one moment of time directly. The moment of time which I experience directly I term the present moment, and I distinguish this present moment from moments which I have experienced previously, which I term past moments, and moments which I have yet to experience, which I term future moments.

If I walk along the path traversed by the arrow, I can stop fifteen metres from the target and say "I am here". Whilst my spatial location is fifteen metres from the target, a location six metres from the target does not seem to be any less real than my current location. It does not seem that the location fifteen metres from the target is real simply because that is where I am located, nor that the location six metres from the target is not real because I am not located at that point in space or because, perhaps, I am not observing that point in space. I can summarize by saying that a location in space is objective, that is, it is real independent of whether or not I am located at that point in space and independent of whether or not I am observing that location in space.[2]

To say that something is *objective* is to say that it does not belong to the consciousness or the perceiving or thinking subject, but to what is presented to the subject. An objective thing is therefore a thing which is external to the mind.[3] I am going to assume a realist position in relation to locations in space and assume that they are objective in this sense.[4]

Suppose that I am standing at the position fifteen metres from the target at a moment of time one hundred and eighty seconds after the arrow reached the target, and I say "I am here now". My temporal location is the moment one hundred and eighty seconds after the arrow reached the target. Just as I can envisage a location in space, so

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[1] In the case of simple distance against time graphs, distance is often represented on the *y*-axis with time represented on the *x*-axis. In the following chapters, however, I will be referring to the type of space-time diagrams which are standardly employed in accounts of special and general relativity. The convention in these type of space-time diagrams is to represent time on the *y*-axis and distance on the *x*-axis. This convention has therefore been adopted from the outset.

[2] It is possible to conceive of metaphysical systems in which the reality of locations in space *does* depend upon their being observed. An idealist in the mould of Bishop Berkeley might hold, for example, that spatial locations only exist because they are observed by God. However, I am assuming for the sake of argument a straightforward realist view in which a spatial location is assumed to be real, regardless of whether or not anyone is located at that point in space and regardless of whether or not that point in space is being observed by an observer.

[3] This definition is derived from the entry for "objective" in the Oxford English Dictionary.

I can envisage a location in time, and just as I can envisage that a location in space is objective, so I can envisage that a location in time is objective. I will therefore assume, again adopting a straightforward realist view, that there is an objective correlate to what I experience as the present moment of time, and that this objective correlate is a location in time. I will use the term *moment* to refer to the objective correlate of my experience. I am therefore taking a moment to be an objective temporal location, and assuming that my experience of the present moment is an experience of a particular temporal location.

A question arises as a consequence of the realist assumption made above. Is the moment at which the arrow reached the target as real as the moment which I call "now"? From my point of view, the moment at which the arrow reached the target is a past moment, a moment which I cannot perceive directly, though I may be able to remember it. Does that, however, mean that I should consider it to be less real than the moment which I am experiencing as the present moment?

In relation to a particular spatial location, the fact that I am at that spatial location does not appear to confer any special status upon that location which distinguishes it from other locations in space. According to the straightforward realist view I am assuming, all spatial locations have the same physical status and they also all have the same existential status.

By "existential status" I mean the "state of existence" of a spatial location (and, as I will go on to illustrate, the "state of existence" of a temporal location as well). In order to indicate the distinction I am drawing here between physical status and existential status, consider an unrelated example. When Descartes considered a piece of wax,[5] he noticed that its physical status could vary. It could exist, in the scenario he describes, as a solid or a liquid. The wax in these two different states could be said to have a different physical status. If the wax actually went out of existence, however, if it boiled away into its constituent components for example, then I would describe this by saying that it had a different existential status before and after boiling. Before boiling it existed as wax, after boiling it no longer existed as wax. In this case, it is apparent that if the wax has a different existential status, then it necessarily has a different physical status, suggesting that a change in existential status is a subset of the possible changes in physical status. Indeed, change in existential status could be viewed as a limiting case of change in physical status. Whilst this example clarifies in essence the distinction

[4] Nagel 1986 explores the philosophical complexities attendant on the term "objective" in detail.
[5] Descartes 1641, 2nd Meditation.

which I am drawing between physical status and existential status, I will attempt to clarify the distinction further specifically as it applies to spatial and temporal locations.

The claim that a spatial location exists whether or not a subject is located at that location is a relatively unproblematic one, unless one is an idealist. (By a *subject* here is meant an entity capable of experiencing the location at which it is located.) Should I therefore assume, however, that a temporal location exists, whether or not a subject is located at that location? Given that the only temporal location of which I have direct experience is the present moment, it is not clear what I am entitled to assume about the state of existence of other temporal locations, that is, past and future moments. I employ the term "existential status" at this stage, therefore, to avoid embodying in the terminology any assumptions which have not yet been justified.

In relation to a particular spatial location, my being at that spatial location did not carry any particular significance for either the existential status nor more generally the physical status of that location, on the assumption that all spatial locations are objective. In relation to a particular temporal location, however, it is not yet obvious what the significance is of my being at that temporal location.

Should I conceive of a temporal location in the same way as a spatial location, and conclude that the fact that I am "at" that temporal location, that is, that I experience that temporal location as the present moment, does not imply any special existential status nor, more generally, any special physical status for that temporal location which distinguishes it from other locations in time? Or should I note that my experience of time is different to my experience of space, and conclude that the fact that I experience a particular moment as the present moment is indicative of an objective difference between that moment and other moments of time? If the latter, should I conclude that the difference is an existential difference, or some other physical difference between that moment and other moments of time?

In the case of a piece of wax, it was clear that a change in existential status amounted to a change in physical status, of a more extreme variety than other possible changes in physical status such as when the wax changes from a solid to a liquid. I am going to assume that, similarly, if two moments of time had a different existential status, then this would imply that they had a different physical status. It seems apparent, however, that two moments of time could have a different physical status without their having a different existential status, just as solid wax has a different physical status to liquid wax, although it shares the same existential status.

On what basis, however, am I entitled to draw any conclusions as to the physical status or more specifically the existential status of a moment of time?

2 *Static Block Universe And Objectively Distinguished Present Theories Of Temporal Metaphysics*

In the following chapters, I am going to investigate broadly two different ways of conceiving of locations in time. In particular I am going to assess whether our current theories of physics imply that we should conceive of locations in time in one of these ways in preference to the other way. In this section, therefore, I will map out what I take the two ways of conceiving of locations in time to be. One way of conceiving of locations in time is found in what I will term *static block universe* theories, the other way of conceiving of locations in time is found in what I will term *objectively distinguished present* theories. I am going to focus on three types of objectively distinguished present theory, although in fact more than three types of objectively distinguished present theory can be identified.[6] In the following subsections I will explain the terminology which I have adopted, and also relate it to other terminology widely employed in relation to temporal metaphysics.

(a) Static Block Universe Theories

What I am calling static block universe theories are frequently referred to simply as block universe theories.[7] I have qualified the term *block universe* by addition of the adjective *static* in order to distinguish these theories from *growing block universe* theories, which I describe below as a subset of objectively distinguished present theories. The description of block universes as specifically static block universes is also suggested by the title of chapter 3 of Dainton 2001, the chapter entitled "Static Time".

The claim which characterizes a theory of temporal metaphysics as a *static block universe* theory is the claim that all locations in time share the same existential status. That is to say, in a static block universe, moments of time which some arbitrary observer calls past moments exist in the same way as moments of time which the same arbitrary observer calls future moments, and both these types of moment exist in the same way as that moment of time which the same arbitrary observer calls the present moment. This type of view is expressed by Dainton as follows.

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[6] Confer Lucas 1989.

[7] Confer Sider 2001, p.11.

> "Many contemporary philosophers are convinced that McTaggart was essentially correct: our world is a static four-dimensional ensemble, lacking a moving present, wherein all times and events are equally real." (Dainton 2001, p.27)

I take Dainton to mean by *times* here what I am referring to as *moments* of time or *locations* in time. In a static block universe, as portrayed here by Dainton, the temporal dimension is composed of a series of moments, all of them equally real, just as the three spatial dimensions are composed of a series of locations in space, all of them equally real.

An interesting question arises in relation to static block universe theories, in light of the distinction which I have drawn between the physical status of a location in time and the existential status of a location in time. Is an advocate of a static block universe theory committed to the claim that all locations in time share the same physical status[8]? Apparently not. It is possible to imagine that all locations in time share the same existential status, a view to which I take it any advocate of a static block universe theory is committed, without necessarily concluding that they all share the same physical status. (Recall the example of the wax. The liquid wax has a different physical status to the solid wax, but both samples of wax have the same existential status.)

Why might an advocate of static block universe theory wish to maintain that locations in time do not all have the same physical status? An advocate of a static block universe theory claims that my experience of the passage of time, the passing of the present moment into past moments and of future moments into the present moment, is a consequence of the way in which I experience the physical world, and does not reflect any objective difference in the existential status of locations in time. However, an advocate of a static block universe theory need not claim that my experience of the passage of time does not relate to any objective features of the physical world at all.

On a static block universe view, I am composed of a sequence of temporal parts, arranged along the temporal dimension. Each of these temporal parts has the experience of the temporal location at which it is located as the present moment. All of these temporal locations have the same existential status, but it is conceivable that each temporal location has a different physical status to every other temporal location, and

[8] Some philosophers might prefer to use the term "metaphysical status" rather than the term "physical status" in relation to locations in time. However, I am assuming that those philosophers who turn to theories of physics as a source of temporal metaphysics, the type of philosophers with whom I will be most concerned in this thesis, are conceiving of the difference or similarity between locations in time as

that this is why each of the temporal parts of which I am composed experiences the temporal location at which it is located as a different moment to any other moment.

The proposed model is one in which all locations in time exist. A subject who experiences the passage of time is composed of a sequence of temporal parts arranged along a sequence of locations in time. Each temporal part of the subject experiences the location in time at which it is located as the present moment, but the physical status of each location in time is different to the physical status of every other location in time. As a consequence, no two locations in time are experienced as the same moment, and the subject expresses this difference between locations in time by speaking of the passage of time. Objectively, however, the physical status of each location in time does not change: there is no "moving present".

What is not clear in the model as described is in what respect the physical status of one temporal location might be different to the physical status of another temporal location. The important point to note at this stage, however, is that allowing that the physical status of one temporal location can be different to the physical status of another temporal location may provide a basis for explaining the experience of the passage of time in a static block universe, without undermining the claim, central to any static block universe theory, that there is no difference in the existential status of temporal locations.

Static block universe theories are sometimes referred to as *B-series* theories, since the temporal dimension in a static block universe corresponds to a temporal series famously referred to by the early twentieth century philosopher J. M. E. McTaggart as the B-series.[9] McTaggart describes two temporal "series" of events, the A-series and the B-series.[10] In the A-series, each event has the property of being past, present, or future. An event which is future (that is, which has the property of being future), becomes present, then becomes past. The temporal properties of events in the A-series therefore change.

In the B-series, an event has the properties of being before or after other events.

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ultimately a physical difference or similarity. Hence I shall speak in terms of the physical status of locations in time.

[9] Confer McTaggart 1927.

[10] The term "event" is potentially a problematic term, particularly in the context of temporal metaphysics. (Confer Davidson 1980, essays 9 and 10.) I take an event to be a change or changes undergone by one or more physical entities over a sequence of moments of time. It would I think be preferable to talk about a state of affairs, the arrangement of a collection of physical entities at a particular moment of time, having the property of being past, present or future, since some stages in an event could be past and future whilst one stage of the same event was present. I retain the term "event" here however since this is the term used by McTaggart.

If one event is after another event, then this remains the case relative to all other events in the B-series. The temporal properties of events in the B-series therefore do not change.

McTaggart also alludes to a C-series which gives rise to our experience of events as temporally ordered, and hence to the apparent existence of the A-series and B-series. The C-series itself however is beyond our experience, somewhat like Kant's *Ding an Sich*, and therefore, although McTaggart implies that it is ordered, it is misleading to describe this ordering as temporal.

Static block universe theories embody the claim that the properties of being past, present or future associated with events in the A-series are a consequence of our experience of what is essentially a B-series, and thus that A-series properties are not actually possessed by real events.

With reference to the possibility that the physical status of one location in time may be different to the physical status of another location in time in a static block universe, it can be observed that some account needs to be given of what makes one location in time earlier than another location in time where those locations in time lie in a B-series. It may in fact be that any such account would need to be given in terms of the physical status of locations in time. Therefore, it may not simply be that an advocate of a static block universe theory *can* allow that the physical status of one location in time can be different to the physical status of another location in time, but is actually *required* to allow this, in order to explain the B-series ordering of these locations in time.

Before concluding this description of static block universe theories, I will indicate some of the other terms which are used to describe such theories.

The terms *four dimensionalism* and *eternalism* are both employed to refer to static block universe theories.[11] The term *four dimensionalism* arises out of the implied equivalence between the temporal dimension and the three spatial dimensions in a static block universe.

The term *eternalism* arises out of the observation that each location in time (and the temporal parts of the objects associated with that location in time) has properties which never change but are eternally fixed in a static block universe.

Static block universe theories are also referred to as *tenseless* theories.[12] In order to understand what is meant by a tenseless theory of time, consider first the following

[11] Confer Sider 2001.
[12] Confer Le Poidevin 1991, Hawley 2001.

depiction of a *tensed* theory, the opposite of a tenseless theory.

> "[*Tensed* theories] assume that time flows, i.e. that times [that is, locations in time or moments of time], and objects located at them, successively possess the transient monadic properties of being future, present and past, properties which I shall follow the custom of calling 'tenses'. (These properties must not of course be confused with the variations in the spelling of verbs in English and some other languages that grammarians also call 'tenses'.)"[13] (Mellor 1998, pp.45-6)

A tenseless theory, then, is any theory which denies that locations in time successively possess the transient monadic properties of being future, present and past. This is equivalent to denying the existence of McTaggart's A-series.

Since, in a static block universe, locations in time do not possess tenses in the philosophical sense of that term described by Mellor, an alternative name for a static block universe theory is a tenseless theory.

To conclude this section, I provide the following summary of the beliefs embodied in a static block universe theory. I have added points (vii) to (x) to indicate how physical objects are conceived of in a static block universe theory. This is not intended as an account of every belief which an advocate of a static block universe theory might hold, but rather a summary of what I take to be the main beliefs.

Summary Of The Beliefs Embodied In A Static Block Universe Theory

(i) All locations in time share the same existential status, that is, all locations in time exist.

(ii) Locations in time may not all have the same physical status.

(iii) Whatever the physical status of a location in time, it has this status eternally.

(iv) Given two different locations in time, one location must be earlier than the other location.

(v) The property "earlier than" may be explicable in terms of the different physical status of locations in time.

[13] Confer Mellor 1998. Mellor is actually ascribing the assumption that time flows to Kant when he is arguing in the First Antinomy that time "can neither lack nor have a first moment". Confer Kant [1929], pp. 396-7. However, Mellor's description of what the assumption embodies is a good description of a tensed theory of time. The quotation is useful because it clarifies the distinction between the philosophical and grammatical uses of the term *tense*.

(vi) The experience of the passage of time by an inhabitant of a static block universe may be explicable in terms of the different physical status of locations in time.

(vii) An object is composed of temporal parts.[14]

(viii) One temporal part of an object exists at one location in time.

(ix) Any object composed of a single temporal part is a three-dimensional entity.

(x) Any object composed of two or more temporal parts is a four-dimensional entity.

Whenever I use the term *static block universe theory* in the following pages, I will mean the collection of beliefs stated above, unless specifically stated otherwise.

(b) Objectively Distinguished Present Theories

The claim which characterizes a theory of temporal metaphysics as an *objectively distinguished present* theory[15] is the claim that there are objective differences between locations in time, and that, in particular, that location in time which I experience as the present moment is objectively distinguished from all other moments of time.

An advocate of an objectively distinguished present theory claims that the distinction which we make between past, present and future moments of time on the basis of our experience reflects an objective difference between locations in time, a difference which actually obtains in the universe which we inhabit.

Since the distinction which we draw between past, present and future moments of time arises out of our experience of the passage of time, objectively distinguished present theorists also claim that our experience of the passage of time is correlated to objective conditions in the universe which we inhabit, objective conditions which are in some way related to the objective distinction between locations in time.

According to advocates of an objectively distinguished present theory, it can be deduced from the fact that we experience the passage of time, that is, from the fact that we experience an ever changing present, that each location in time which we experience as the present moment does not constitute a present moment eternally, but only

[14] I have included a belief in temporal parts (belief (vii)) and some further beliefs connected to this belief (beliefs (viii), (ix) and (x)) as characteristic of Static Block Universe Theories. However, some theorists who reject Objectively Distinguished Present Theories, and who might therefore reasonably be described as Static Block Universe Theorists, also reject temporal parts for objects. Confer for example Mellor 1981, Mellor 1998. This suggests that there are at least two types of Static Block Universe Theory, those embodying belief in temporal parts and those not embodying belief in temporal parts. I have not sought to distinguish between these two types of Static Block Universe Theory for the purposes of this thesis, but it is important to note that the distinction exists.

[15] The term *objectively distinguished present* is my own. I use it to refer to all theories of temporal metaphysics which are not static block universe theories.

transiently. In a static block universe, if a location in time has a set of properties, it has those properties eternally (hence, as illustrated above, an alternative name for static block universe theories is eternalism). In contrast, in a universe where one location in time is objectively distinguished as the present moment, that particular location in time is not objectively distinguished as the present moment eternally, but only transiently. There is thus a "moving present" in objectively distinguished present theories.

Advocates of an objectively distinguished present theory are claiming at the very least that there can be a difference in the physical status of locations in time. As we saw, static block universe theorists can also claim that there can be a difference in the physical status of locations in time. The difference between the two types of theory is as follows. In a static block universe, if there is a difference in the physical status of two locations in time, that difference is eternal. Furthermore, all locations in time are conceived of as having the same existential status in a static block universe.

In a universe in which an objectively distinguished present exists, however, the difference in the physical status of locations in time need not be eternal. A location in time has a different physical status when it is in the future or the past of some arbitrary observer to when it becomes the present moment of that observer. It may or may not have a different physical status when it is in the future of the arbitrary observer to when it is in the past of the arbitrary observer.

Frequently, the difference in the physical status of locations in time in objectively distinguished present theories is interpreted as a difference in the existential status of locations in time. The first two types of objectively distinguished present theory which I consider below both envisage the objective difference between that location in time which I experience as the present moment and other locations in time in terms of the state of existence of those locations in time. However, it is possible to conceive of the objective difference between locations in time in terms of a difference in the physical status of those locations in time, whilst maintaining that all locations in time have the same existential status. This becomes apparent in the third type of objectively distinguished present theory which I consider.

Hawley summarizes the distinction between the objectively distinguished present type of theory and the static block universe type of theory in terms which echo McTaggart's formulation.

> "Tenseless [static block universe] theorists believe that events are related by being earlier, later than or simultaneous with one another; tensed [objectively

distinguished present] theorists believe that an important further feature of an event is whether it is past, present or future." (Hawley 2001, p.33)

Since objectively distinguished present theories embody the claim that the properties of being past, present or future associated with events in McTaggart's A-series are real ones, an alternative name for objectively distinguished present theories in general are *A-series* theories.[16]

Since objectively distinguished present theories embody the equivalent claim that locations in time successively possess the transient monadic properties of being future, present and past, customarily called tenses, another alternative name for objectively distinguished present theories in general are *tensed* theories. [17]

I will now consider three types of objectively distinguished present theories, beginning with the type against which advocates of static block universe theories frequently direct their arguments.

(i) Presentist Theories

All advocates of objectively distinguished present theories assert that there is a physical distinction between locations in time, some assert that this physical distinction is an existential distinction. That is, some advocates of objectively distinguished present theories claim that some locations in time have a different existential status to other locations in time.

Theories of an objectively distinguished present which assert that only one location in time exists, namely that location in time which I experience as the present moment, are frequently referred to as *presentist* theories.[18] According to such theories, the moment which I experience as the present moment is the only existing moment.

Sider depicts a presentist theory in terms of the existential status of objects in the following quotation. Note that he equates existing with being real here. I will argue in the next chapter that this equation needs to be analyzed, on the grounds that asserting that something is real may not unequivocally imply that it exists. Does the claim that the past is real, for example, equate to the claim that the past exists? I will return to this issue in the next chapter.

[16] Confer McTaggart 1927 and section (a) above.
[17] Confer Mellor 1998 and section (a) above.
[18] Bigelow 1996, Zimmerman 1996, and Sider 2001 all refer to presentist theories.

> "Only currently existing objects are real … the past is no more, while the future is yet to be." (Sider 2001, p.11)

Whilst Sider captures the essence of the presentist position, I have attempted in the following description to provide a definition of presentism (that is, of the presentist position), based on Sider's description but couched in terms of locations in time, and without reference to objects being real.

> "The only objects which exist are those objects which exist at the location in time which are experienced as the present moment. Locations in time which have previously been experienced as the present moment no longer exist, whilst locations in time which have not yet been experienced as the present moment do not yet exist."

Sider goes on to question whether it is possible to coherently formulate the presentist claim that objects wholly exist in the present moment. He cites Dau's description of presentism, which Dau refers to as "the three-dimensional conception".

> "On the three-dimensional conception, the entire object is to be found at each instant that it exists." (Dau 1986, p.464, quoted in Sider 2001, p.63)

Sider objects to this type of formulation as follows.

> "What, then, is three-dimensionalism? It cannot be the denial of the possibility of temporal parts, for many three-dimensionalists will admit the possibility of instantaneous objects, objects which appear only for an instant and then disappear. Such objects would be temporal parts of themselves, given the present definition of 'temporal parts'." (Sider 2001, p.64)

Whilst it is well to be aware of this potential problem for presentism, it may be that Sider is employing a definition of a temporal part which not all presentists would be prepared to accept when he claims that instantaneous objects would be temporal parts of themselves.

It seems that a presentist could assert that if an object exists at a location in time, then it exists wholly at that moment, as described by Dau. This is simply to deny that objects have temporal parts. Whether the claim that an object exists wholly at a single location in time is a coherent one remains problematic, however.

Setting aside this problem at this stage, the following beliefs can be identified as lying at the heart of any presentist theory of temporal metaphysics. I derive these beliefs from the definition of presentism given above, which was in turn derived from Sider's description of presentism. Notice however that points (iv), (v) and (vi) are implied by, rather than derived directly from, the earlier definition of presentism. Points (iv) and (v) are required to express the presentist belief in a moving present. Point (vi) indicates that a B-series is definable in a presentist theory. This summary of beliefs is not intended as a complete account of every belief to which an advocate of a presentist theory might be committed.

Summary Of The Beliefs Embodied In A Presentist Theory

(i) Only one location in time exists, that location in time which is experienced as the present moment.

(ii) Locations in time which have previously been experienced as the present moment, that is, past moments, no longer exist.

(iii) Locations in time which have not yet been experienced as the present moment, that is, future moments, do not yet exist.

(iv) The location in time which I experience as the present moment does not exist eternally, but transiently.

(v) As that location in time which I have just experienced as the present moment passes out of existence, so a new location in time passes into existence.

(vi) Although one location in time can be referred to as earlier than another location in time, at most one of the two locations referred to actually exists.

(vii) An object exists wholly at that location in time which is experienced as the present moment.

(viii) All objects are three-dimensional.

Whenever I use the terms *presentist theory* or *presentism* in the following pages, I will mean the collection of beliefs stated above, unless specifically stated otherwise.

(ii) Growing Block Universe Theories

As we have just seen, presentists claim that only that location in time which is experienced as the present moment exists. This is not the only theoretical position open 0to advocates of objectively distinguished present theories, however. An alternative approach is to conceive of the location in time constituting the present moment as the boundary between existing moments, the past, and non-existing moments, the future.[19] This type of theory is sometimes termed a *growing block universe* theory.[20]

The present moment is again envisaged to be objectively distinguished from other moments of time, but rather than claiming that the present moment is the only existing moment, a growing block universe theorist claims that the present moment is the moment which is just coming into existence, in addition to all past moments which exist. The total number of existing moments is therefore constantly increasing.

Sider expresses the growing block universe view as follows.

> "Intermediate between the polar opposites presentism and eternalism is the view, defended by C.D. Broad (1923, ch.II) and more recently by Michael Tooley (1997), that the past is real but the future is not. On this view reality consists of a growing four-dimensional manifold, the 'growing block universe'." (Sider 2001, p.12)

This can be reformulated as follows in terms of locations in time, and in terms of existence rather than reality.

> "A growing block universe is one in which locations in time which have previously been experienced as the present moment, that is, past moments, exist, but locations in time which have not been experienced as the present moment, that is, future moments, do not exist. On this view, the number of locations in time which exist is increasing."

[19] There is a potential problem around linguistic tense in any attempt to express the status of moments of time. Classifying a moment as "existing" or "non-existing", where that moment is not the present moment, entails using a part of speech which might be interpreted as implying existence in the present. This can be avoided by interpreting terms such as "existing" or "non-existing" tenselessly when they are applied to moments of time other than the present moment. Compare the present tense sense of "is" in the proposition "She is here now" with the tenseless sense of "is" in the proposition "thirteen is a prime number". The problem does not arise for presentists, since they assert that only the present moment exists.

[20] Dainton 2001 and Sider 2001 both refer to growing block universes.

A number of philosophers have questioned the coherence of growing block universe theories. A frequent complaint against such theories is that it is not clear how that location in time which is experienced as the present moment is to be distinguished from locations in time which constitute past moments. Braddon-Mitchell frames this problem in terms of agents, that is, subjects capable of acting. Since past locations in time exist, agents located at those past moments also exist. He therefore questions on what basis an agent is entitled to conclude that the location in time which he or she is experiencing as the present moment actually is the present moment. Might it not be that the agent actually exists at some moment which is past relative to some other agent who is located at the actual present moment? The implication is that growing block universe theories must collapse into incoherence.

> "Like presentism [a growing block universe] has an objective now, but unlike presentism the existence of past agents undermines any reason those who are present might have for believing they are present." (Braddon-Mitchell, p.202-3)

A possible way of avoiding this problem is to assert that we experience as the present moment only a location in time which is coming into existence, not a location in time which fully exists. On this view, an agent existing at a past moment in a growing block universe, a moment which fully exists, would have no experience of that location in time as a present moment. Only an agent existing at the actual present moment, that moment which is coming into existence, would experience a present moment.

Whilst acknowledging this problem for a growing block universe theory, my main purpose here is to describe the essential components of such a theory. The following, therefore, is a summary of the main beliefs embodied in a growing block universe theory.

Summary Of The Beliefs Embodied In A Growing Block Universe Theory

(i) That location in time which is experienced as the present moment is the location in time which is coming into existence.

(ii) Locations in time which have previously been experienced as the present moment, that is, past moments, remain in existence.

(iii) Locations in time which have not yet been experienced as the present moment, that is, future moments, do not yet exist.

(iv) The location in time which I experience as the present moment is not coming into existence eternally, but transiently.

(v) As that location in time which I have just experienced as the present moment becomes a past moment, so a new location in time comes into existence.

(vi) The total number of locations in time existing in the universe is increasing.

(vii) One location in time can be referred to as earlier than another location in time.

(viii) An object is composed of temporal parts.

(ix) One temporal part of an object exists at one location in time.

(x) Any object composed of a single temporal part is a three-dimensional entity.

(xi) Any object composed of two or more temporal parts is a four-dimensional entity.

(xii) The total number of temporal parts constituting an object increases by one if a new temporal part of the object comes into existence at the location in time which is coming into existence, that is, the present moment.

Whenever I use the term *growing block universe theory* in the following pages, I will mean the collection of beliefs stated above, unless specifically stated otherwise.[21]

(iii) Growing Determinacy Theories

Presentist theories and growing block universe theories both conceive of the difference between the present moment and past and future moments of time consisting in a difference in the existential status of those locations in time. However, it is possible to conceive of the difference between locations in time consisting in a difference in their physical status, whilst maintaining that all locations in time have the same existential status, that is, that all locations in time exist. One aspect of the physical status of a location in time which could vary is its state of determinacy. I shall refer to the type of objectively distinguished present theory in which the determinacy of locations in time is conceived of as varying as a *growing determinacy* theory.

What do I mean when I talk about the determinacy of a location in time? Why do I refer to the third type of objectively distinguished present theory as a growing determinacy theory? In order to answer these questions, I will begin by examining the meaning of the terms *determinate* and *indeterminate*.

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[21] Lucas 1989 identifies at least one other possible type of objectively distinguished present theory, in which all future moments of time exist, and the present moment is that location in time at which locations in time go out of existence rather than, as in a growing block universe theory, that location in time at which locations in time come into existence. I am not going to consider this type of theory since very few philosophers have proposed this type of theory as their preferred temporal metaphysics.

Suppose that I am experiencing the location in time t_n as the present moment. Consider the following proposition.

(1) At the present moment, either it is raining or it is not raining.

I will use p to symbolize the proposition "it is raining". I will introduce the symbol @ to indicate the location in time at which the proposition is uttered, so that I can use $@t_n$ to symbolize the temporal reference "at the present moment". I will therefore represent (1) as follows.

(1*) $@t_n\text{: } p \vee \neg p$

The law of excluded middle says that, for any proposition p, the proposition $p \vee \neg p$ is true as a matter of logical necessity.[22] Using $\Box$ to indicate logical necessity, I could also write the following therefore.

(1**) $@t_n\text{: } \Box(p \vee \neg p)$

From this proposition, I can deduce that either p is true at t_n or $\neg p$ is true at t_n, that is, either it is raining at the present moment or it is not raining at the present moment. This can be deduced directly from (1*), in fact, without reference to the necessity of the truth of $p \vee \neg p$.

I am going to assume that my entitlement to deduce that either p is true at t_n or $\neg p$ is true at t_n derives from the assumption that t_n, the present moment, is determinate. I will therefore introduce the following principle. If the location in time t_n is determinate then the proposition $@t_n\text{: } p \vee \neg p$ implies that either p is true or $\neg p$ is true at t_n. I will represent this principle symbolically as follows, and label it (N) for "now".

(N) $\{(t_n \text{ is determinate}) \wedge (@t_n\text{: } p \vee \neg p)\} \Rightarrow \{@t_n\text{: } (p \text{ is true}) \vee (\neg p \text{ is true})\}$

The claim that either p is true or $\neg p$ is true is essentially equivalent to the principle of bivalence, which states that every proposition is either true or false. The

[22] This description of the law of excluded middle is adapted from Flew 1979. Expressed in the terminology of possible worlds, the law of excluded middle says that $p \vee \neg p$ is true in all possible worlds.

principle of bivalence claims that every proposition has a truth value, and that there are just two possible truth values, true and false. Provided that a negation operator is introduced, the principle of bivalence entails the law of excluded middle, but it is not equivalent to it. The law of excluded middle is a law of logic and is therefore true, if it is true at all, regardless of what the proposition p is taken to mean. The principle of bivalence, on the other hand, is a semantic principle which applies to the interpretation of the proposition p, rather than to the logic of the use of the symbol.[23]

Assuming, as before, that p symbolizes "it is raining", what would make p true at t_n? If a correspondence theory of truth is assumed, then p is true if a state of affairs which amounts to the falling of rain obtains at t_n. Evidently, to avoid contradiction, p would need to include, or be interpreted as implying, reference to a spatial location, since it could be raining in some locations and not in others at t_n. Thus we could interpret p as implying "it is raining (at the spatial location where this proposition is uttered)".

I am also going to suggest that, in the context of explaining what is meant when a location in time is described as determinate, p needs to include, or be interpreted as implying, reference to a temporal location. I am going to interpret p, in the example which I have been considering, as implying "it is raining (at the spatial location where this proposition is uttered and at the temporal location when this proposition is uttered)". In general, I am only going to allow p to symbolize propositions which describe states of affairs at the temporal location at which p is uttered. The reason for this restriction will become apparent in the course of considering the state of determinacy of locations in time which are past or future relative to the location in time which I am experiencing as the present moment.

On the basis of what has been said so far, the assumption that a location in time is determinate can be seen to amount to the assumption that all propositions describing possible states of affairs at that location in time are either true or false.

I have assumed so far that the present moment of time, t_n, is determinate, and that this assumption entitles me to deduce from $@t_n$: $p \vee \neg p$ that either p is true at t_n or $\neg p$ is true at t_n. I am now going to further assume that all past locations in time are determinate. By a past location in time I mean a location in time which is earlier than the location in time which I am experiencing as the present moment. I will denote an arbitrary location in time which is earlier than the present moment t_n by the expression

[23] This description of the principle of bivalence is adapted from Flew 1979.

t_n-Δt. Since I am assuming that all past locations in time are determinate, I am effectively saying that I am prepared to deduce the principle of bivalence from the law of excluded middle at any past location in time. I can express this symbolically as follows, using the label (P) for past.

(P) $\{(t_n\text{-}\Delta t \text{ is determinate}) \wedge (@t_n\text{-}\Delta t\text{: } p \vee \neg p)\} \Rightarrow \{@\ t_n\text{-}\Delta t\text{: } (p \text{ is true}) \vee (\neg p \text{ is true})\}$

Notice, given the stipulation made earlier, that p can only describe a state of affairs at the location in time t_n-Δt.

I am now going to postulate that all future locations in time are *indeterminate*. By a future location in time I mean a location in time which is later than the moment in time which I am experiencing as the present moment. I will denote an arbitrary location in time which is later than the present moment t_n by the expression $t_n+\Delta t$. Since I am assuming that future locations in time are indeterminate, I am no longer prepared to deduce the principle of bivalence from the law of excluded middle at any future location in time. I can express this symbolically as follows, using the label (F) for future.

(F) $\{(t_n+\Delta t \text{ is indeterminate}) \wedge (@t_n+\Delta t\text{: } p \vee \neg p)\} \not\Rightarrow \{@\ t_n+\Delta t\text{: } (p \text{ is true}) \vee (\neg p \text{ is true})\}$

Once again, given the stipulation made earlier, p can only describe a state of affairs at the location in time $t_n+\Delta t$.

What (F) implies, assuming once again a correspondence theory of truth, is that there is no state of affairs at a future location in time $t_n+\Delta t$ which would make proposition p either true or false, where proposition p describes a state of affairs at that future location in time $t_n+\Delta t$.

Evidently (F) would not necessarily hold if p could refer to a past state of affairs. From the proposition "It was raining two days ago or it was not raining two days ago", uttered tomorrow, I am prepared to deduce that either it is true that it was raining yesterday or it is false that it was raining yesterday. Hence the need to stipulate that p can only describe a state of affairs in the location in time at which it is uttered.

Given the above, the assumption that a location in time is indeterminate can be seen to amount to the assumption that not all propositions describing possible states of affairs at that location in time are either true or false. If a location in time is described as *absolutely indeterminate*, then this should be interpreted as implying that no propositions describing possible states of affairs at that location in time are either true or false. If a location in time is described as *partially indeterminate*, then this should be interpreted as implying that not all propositions describing possible states of affairs at that location in time are either true or false.

I am now in a position to explain what is meant by a growing determinacy theory of time. I will refer to a location in time as a *moment*. I will call *past moments* those locations in time which are earlier than the location in time which I am experiencing as the present moment, I will call the *present moment* that location in time which I am experiencing as the present moment, and I will call *future moments* those locations in time which are later than the location in time which I am experiencing as the present moment. In a growing determinacy theory, all moments exist. Past moments are regarded as determinate (proposition (P) is assumed) and future moments are regarded as indeterminate (proposition (F) is assumed). The present moment of time is therefore defined in such a theory as that moment which is becoming determinate (proposition (N) is assumed). The theory is called a growing determinacy theory since the number of determinate moments in the universe is growing.

The concept of a growing determinacy theory is not a new one. A number of passages from Aristotle's *De Interpretatione* imply a view of time in which past moments and the present moment are regarded as determinate whilst future moments are regarded as indeterminate. I will consider some extracts from Aristotle in the light of the analysis of the concepts *determinate* and *indeterminate* given above.

> "With regard to what is and what has been it is necessary for the affirmation or the negation to be true or false ... But with particulars that are going to be it is different." (Aristotle, *De Interpretatione* 9)[24]

In this extract, Aristotle is effectively stating that bivalence holds for past moments and the present moment, but does not hold for future moments. The reference specifically to "particulars that are going to be" is a reminder that bivalence holds for a proposition describing universals regardless of the determinacy status of the moment at which the proposition is uttered. The proposition "two plus two equals four" is either true or false regardless of when it is uttered. This is another reason for restricting p in propositions (P), (N) and (F) to symbolizing propositions which describe states of affairs at the temporal location at which p is uttered. Although (P) and (N) would still be valid if p were allowed to symbolize propositions describing the properties of universals, (F) would be invalid.

> "[I]n general, in things that are not always actual there is the possibility of being and of not being ... Clearly, therefore, not everything is or happens of necessity: some things happen as chance has it, and of the affirmation and the negation neither is true rather than the other; with other things it is one rather than the other and as a rule, but still it is possible for the other to happen instead." (Aristotle, *De Interpretatione* 9)

Although this passage amounts to more than just the claim that future moments are indeterminate, it contains the assertion that bivalence fails in relation to future moments, "of the affirmation and the negation neither is true rather than the other", and the passage is therefore a further expression of Aristotle's growing determinacy theory.

> "I mean, for example: it is necessary for there to be or not to be a sea-battle tomorrow; but it is not necessary for a sea-battle to take place tomorrow, nor for one not to take place—though it is necessary for one to take place or not to take place." (Aristotle, *De Interpretatione* 9)

Using p to symbolize "there is a sea battle" and $@t_n+\Delta t$ to symbolize "tomorrow", the two claims which Aristotle is making in this passage can be represented logically as follows.

$$@t_n+\Delta t\colon \Box(p\vee\neg p)$$

$$@t_n+\Delta t\colon \neg(\Box(p) \vee \Box(\neg p))$$

These can be combined to give the following.

$$@t_n+\Delta t\colon \Box(p\vee\neg p) \neq> (\Box(p) \vee \Box(\neg p))$$

[24] Confer Ackrill 1987. The translations of *De Interpretatione* are by Ackrill.

This is very close to, although not quite equivalent to, proposition (F). It constitutes an alternative way of stating the consequence of the assumption that future moments are indeterminate.

> "Clearly, then, it is not necessary that of every affirmation and opposite negation one should be true and the other false. For what holds for things that are does not hold for things that are not but may possibly be or not be; with these it is as we have said." (Aristotle, *De Interpretatione* 9)

This passage implies that although bivalence holds for the present moment, it does not hold for future moments, the import of propositions (N) and (F).

It is worth observing that in this particular passage Aristotle refers to "things that are not". This could be interpreted as an indication that Aristotle is envisaging a temporal metaphysics in which things located in future moments of time do not exist, although this need not necessarily be interpreted as implying that the future moments of time do not exist. Nonetheless, it could be objected to a growing determinacy theory that the only way a future moment of time could be indeterminate would be if that moment of time did not exist at all.[25] In that case, there would be no difference between growing determinacy theories and growing block universe theories.

I have, nonetheless, distinguished growing determinacy theories from growing block universe theories on the grounds that it at least seems conceivable that a moment of time should exist in either an indeterminate state or a determinate state, and that therefore the claim that future moments of time are indeterminate does not logically necessitate the claim that future moments of time do not exist.

If growing determinacy theories are admitted as a possible type of objectively distinguished present theory, it will be observed that they have a fundamental feature in common with static block universe theories. Both growing determinacy theories and static block universe theories assert that all locations in time share the same existential status, namely that all locations in time exist.

However, unlike static block universe theories, growing determinacy theories claim that future locations in time are indeterminate whilst past locations in time are determinate, and furthermore, that there is a dynamic transition of moments of time from indeterminacy to determinacy, the hypersurface at which this transition is occurring constituting that location in time which we experience as the present moment.

Torretti sketches a view along these lines in his assessment of the argument for a static block universe metaphysics on the basis of special relativity.

> "Contingent (i.e. non-necessary) propositions about the future acquire whatever truth values they will have as time goes by. This thesis is obviously tailored to fit the Aristotelian idea of time: The "now" is the omnipresent catalyser that activates transmutation of indeterminate propositions into truth or falsehood." (Torretti 1983, p.249)

Part of the reason for attempting to identify a type of objectively distinguished present theory which is not couched in terms of the existence of moments of time is that, as we will see, many static block universe theorists imply that presentist and growing block universe theories are the only alternatives to static block universe theories. Although many of the arguments used by static block universe theorists against presentist and growing block universe theories would, if valid, also rule out growing determinacy theories, it is nonetheless useful to acknowledge that the state of determinacy of moments of time, rather than the state of existence of moments of time, can serve to distinguish past, present and future moments.

Summary Of The Beliefs Embodied In A Growing Determinacy Theory

(i) All locations in time share the same existential status, that is, all locations in time exist.

(ii) That location in time which is experienced as the present moment is the location in time which is becoming determinate.

(iii) Locations in time which have previously been experienced as the present moment, that is, past moments, are determinate.

(iv) Locations in time which have not yet been experienced as the present moment, that is, future moments, are indeterminate.

(v) The location in time which I experience as the present moment is not becoming determinate eternally, but transiently.

(vi) As that location in time which I have just experienced as the present moment becomes a past moment, so a new location in time becomes determinate.

[25] This objection was drawn to my attention by Roman Frigg.

(vii) The total number of determinate locations in time existing in the universe is increasing.

(viii) One location in time can be referred to as earlier than another location in time.

(ix) An object is composed of temporal parts.

(x) One temporal part of an object exists at one location in time.

(xi) Any object composed of a single temporal part is a three-dimensional entity.

(xii) Any object composed of two or more temporal parts is a four-dimensional entity.

(xiii) Past temporal parts of an object are determinate.

(xiv) Future temporal parts of an object are indeterminate.

Whenever I use the term *growing determinacy theory* in the following pages, I will mean the collection of beliefs stated above, unless specifically stated otherwise.

3 Visualising The Theories Of Temporal Metaphysics

If a moment of time is represented by a two-dimensional slice[26], then we can visualize the differences between the various types of theories of temporal metaphysics, static block universe theories and objectively distinguished present theories, in the manner illustrated in figures 1.2 to 1.5.

Static block universe theorists claim that all moments of time, represented by two-dimensional slices in figure 1.2, have the same existential status. They may have some variation in physical status which forms the basis of the temporal ordering from earlier moments of time to later moments of time. The variation in physical status is represented in the diagram by the ascription of a different number to each moment. There is however no physical basis for describing any particular moment as the present moment, and therefore no physical basis for identifying past or future moments relative to a present moment.

[26] In our universe, we experience three spatial dimensions at any particular moment of time. If we suppress one of these three spatial dimensions, we can represent a universe by a three dimensional object, two of the dimensions being used to represent space and the third dimension being used to represent time. A slice through this universe orthogonal to the time dimension therefore represents a moment of time. A square used to represent a moment of time in figures 1.2 to 1.5 defines an arbitrary boundary on a slice for the purposes of representation, not the spatial extension of the universe.

A Static Block Universe

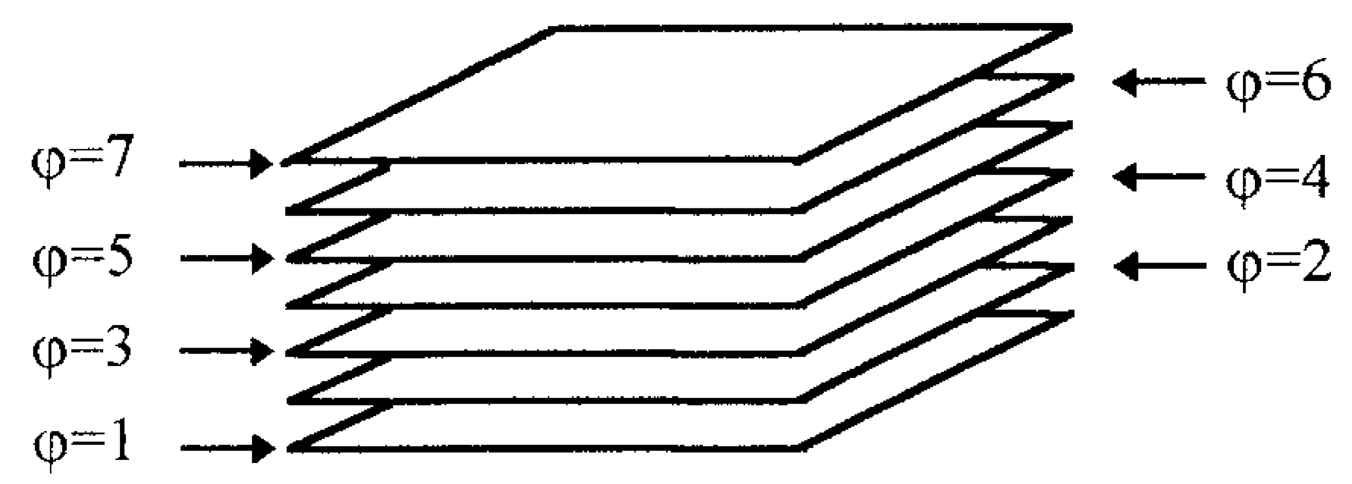

Fig. 1.2 In a static block universe, all moments of time, represented in the diagram above by solid line two dimensional slices, have the same existential status. That is, they all exist. A notional physical property φ is indicated as varying between the moments by assigning a different number to it at each moment. Such a property could form the physical basis of the temporal ordering of the moments from earlier to later.

A presentist claims that the present moment of time has a different existential status to both future and past moments of time, and is in fact the only existing moment of time, as illustrated in figure 1.3.

A Presentist Universe

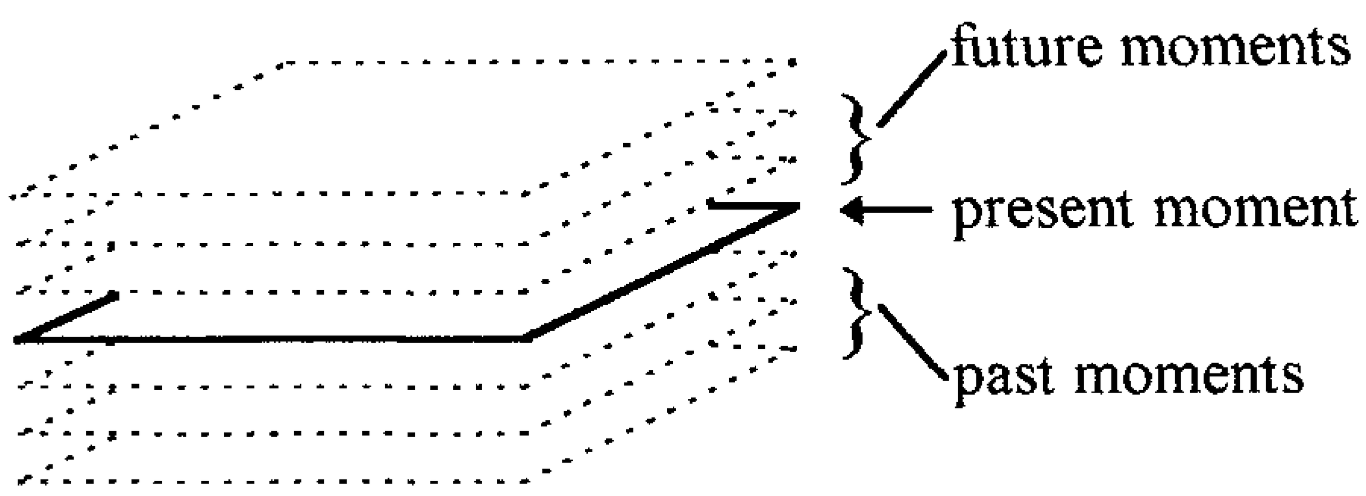

Fig. 1.3 In a presentist universe, the present moment of time is the only existing moment. The existing present moment is represented by a solid line two dimensional slice. Non-existent past and future moments are represented by dotted line two dimensional slices to clarify the position of the present moment.

A growing block universe theorist claims that the present moment is the interface between existing moments which constitute the past, and non-existing moments which "constitute" the future, and is in fact the moment which is just coming into existence, as illustrated in figure 1.4.

A Growing Block Universe

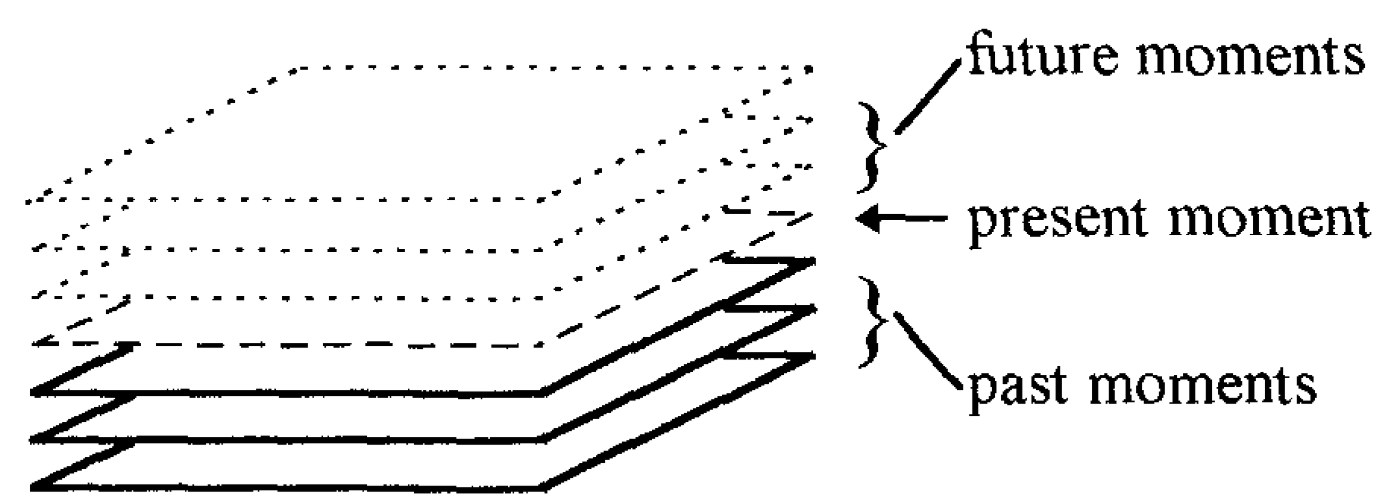

Fig. 1.4 In a growing block universe, past moments of time exist, the present moment of time is coming into existence, and future moments of time do not exist. Existent past moments are represented by solid line two dimensional slices, the present moment coming into existence is represented by a dashed line two dimensional slice, and non-existent future moments are represented by dotted line two dimensional slices.

A growing determinacy universe theorist claims that the present moment of time has a different physical status, but not a different existential status, to other moments of time. Past moments are determinate, future moments are indeterminate, and the present moment is the location in time where the transition from indeterminacy to determinacy occurs[27], as illustrated in figure 1.5.

A Variable Determinacy Universe

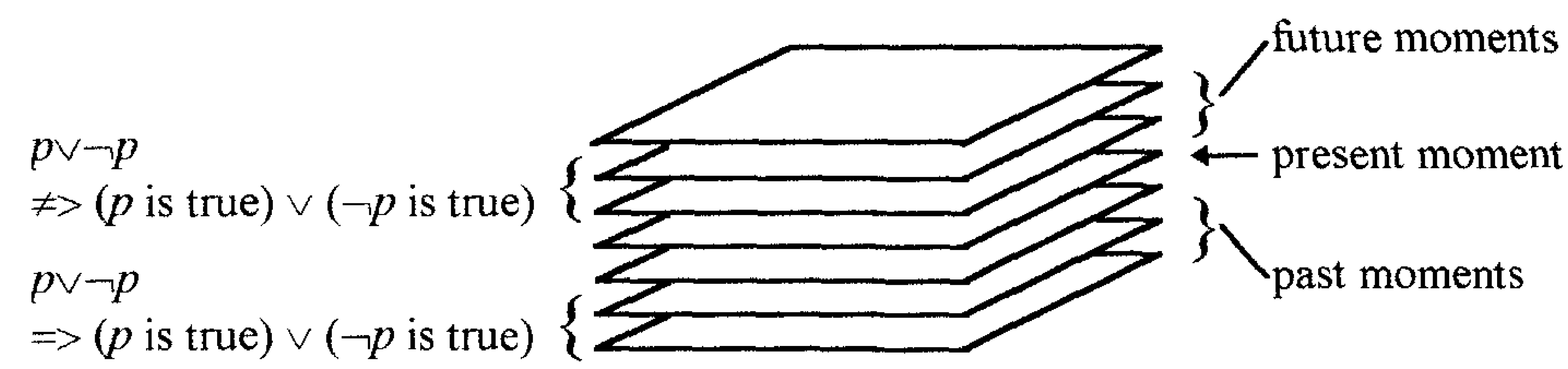

Fig. 1.5 In a variable determinacy universe, past moments of time are determinate, the present moment of time is becoming determinate, and future moments of time are indeterminate. All moments of time exist, hence all moments are represented by solid line two dimensional slices. The distinction between past and future moments can be seen to reside in the state of determinacy of those moments. We are entitled to make a logical deduction in relation to determinate past moments of time which we are not entitled to make in relation to indeterminate future moments of time, and this feature of a growing determinacy universe has been employed to represent pictorially the distinction between past and future moments.

4 Theories Of Physics As A Source Of Temporal Metaphysics

Although, as we have just seen, a variety of different theories of temporal metaphysics are conceivable, we have not yet established any basis on which we might select from amongst them the theory of temporal metaphysics which correctly describes the universe which we inhabit. Since our experience is only ever of the present moment, it

[27] The term "occurs" needs to be understood tenselessly here. Confer footnote 18.

is not obvious how we can select, on the basis of our experience, between a static block universe theory or an objectively distinguished present theory, nor how, if we opt for an objectively distinguished present theory, we can select between the various different types of objectively distinguished present theory available. In an attempt to establish a basis other than our experience on which to select a temporal metaphysics, therefore, some philosophers have looked to theories of physics for guidance.

It can be observed that various theories of physics embody some temporal concepts within them, either implicitly or explicitly, and this observation has led some philosophers to speculate that such theories of physics might imply a particular temporal metaphysics from amongst the various temporal metaphysics which appear to be logically possible. The hope amongst such philosophers is that by analyzing a theory of physics, a theory which has been accepted as a correct[28] description of the universe which we inhabit, we can establish that the theory categorically implies a particular temporal metaphysics, and we can therefore deduce that the temporal metaphysics so implied constitutes, or at least is likely to consitute, the temporal metaphysics of the universe which we inhabit. Over the following chapters I will consider four of the most important theories of modern physics, and the various attempts which have been made by philosophers to establish a temporal metaphysics on the basis of these theories.

(a) Special Relativity As A Source Of Temporal Metaphysics

The branch of physics which has proved most popular amongst philosophers attempting to establish a temporal metaphysics on the basis of a theory of physics is relativity theory. Philosophers have cited both special and general relativity as implying a particular theory of temporal metaphysics, and have in the majority of cases claimed that the theory of temporal metaphysics which is implied by these theories of physics is a static block universe metaphysics.

In chapter 2, I will examine an argument which the philosopher Hilary Putnam[29] formulated with the intention of demonstrating that special relativity implies a static block universe temporal metaphysics. Putnam argues that special relativity implies that past, present and future locations in time, defined relative to some observer, all share

[28] The description "correct" in this context will usually imply that the theory has been used to make predictions and that the outcomes predicted by the theory have been observed under controlled conditions which minimize the possibility of factors not incorporated within the theory bringing about the outcomes which are observed. This understanding of "correct" leaves open the possibility that a correct theory could be replaced by another theory which makes the same predictions but offers other advantages, such as coherence with other theories, over the original theory.

[29] Confer Putnam 1967.

the same existential status. Putnam therefore takes it that special relativity rules out an objectively distinguished present temporal metaphysics.

As we will see, Putnam and other philosophers who argue in favour of a static block universe temporal metaphysics on the basis of relativity theory, both special and general, tend to refer to presentism without acknowledging the other types of objectively distinguished present theory which I identified in section 2 of the current chapter. Philosophers who base their arguments for a static block universe temporal metaphysics on relativity theory may be conceiving of objectively distinguished present theorists as exclusively claiming that the present moment is existentially distinct from past and future moments, or they may be working on the assumption that if it is impossible to unambiguously define a present moment in a universe then it is impossible to describe that universe in terms of any objectively distinguished present theory. Certainly it does seem to be the case that any physical theory which prohibits presentism will necessarily prohibit any objectively distinguished present theory.

In considering Putnam's argument for a static block universe temporal metaphysics on the basis of special relativity, I will assume that Putnam's argument constitutes an argument against presentism, and I will therefore examine what counter arguments, if any, are available to a presentist. I will assume that any successful counter arguments would be equally valid for the other objectively distinguished present theories, namely the growing block universe theories and the growing determinacy theories.

As already indicated, although Putnam's argument is aimed against presentism, it raises problems for the other objectively distinguished present theories as well. Although Putnam's argument is designed only to show that there is no existential difference between moments of time, it would also tend to imply, if successful, that all moments of time are determinate and therefore that can be no difference in the state of determinacy of moments of time. Although growing determinacy theorists accept, along with static block universe theorists, that all moments of time share the same existential status, that is, they all exist, where growing determinacy theorists disagree with static block universe theorists is in asserting that an existing moment of time can be indeterminate, becoming determinate, or determinate. Therefore, if Putnam's argument precludes the possibility of a difference in the state of determinacy of moments of time, it is as problematic for growing determinacy theorists as it is for presentists and growing block universe theorists.

In chapter 2, therefore, I will consider Putnam's argument, and the responses which an objectively distinguished present theorist can make to it.

(b) General Relativity As A Source Of Temporal Metaphysics

In the course of examining Putnam's argument for a static block universe temporal metaphysics on the basis of special relativity, we will observe that there are various problems with the argument. These problems are sufficient to undermine Putnam's conclusion that we are compelled by special relativity to adopt a static block universe temporal metaphysics as the temporal metaphysics of the universe which we inhabit.

In chapter 3, we will see that the logician Kurt Gödel[30] considered an argument for a static block universe temporal metaphysics on the basis of special relativity some eighteen years before Putnam, but dismissed it. Gödel preferred instead to argue for a static block universe temporal metaphysics on the basis of general relativity. Gödel's argument is based upon a set of solutions which he had discovered to Einstein's field equations, the set of equations which constitute the mathematical basis of general relativity. Gödel's solutions model universes, which I will term *Gödelian universes*, which are *time orientable* and *simply connected* but which do not admit foliation[31] by global smooth spacelike hypersurfaces, often referred to in general relativity as *time slices*. Such universes do not admit description by any of the objectively distinguished present theories, since each of these theories requires that a global time slice[32] be identifiable as the present moment.

Gödel argues that Gödelian universes, those universes modelled by his solutions to Einstein's field equations, can only be described in terms of a static block universe temporal metaphysics, since such universes are not describable in terms of an objectively distinguished present theory. He then goes on to suggest if one physically possible universe (that is, one universe which obeys the laws of physics) has a static block universe metaphysics, then all physically possible universes must have the same static block universe metaphysics, apparently on the grounds that the temporal metaphysics of a universe cannot be a contingent matter. He can also be interpreted as making the related claim that even though the universe we inhabit may not have the same topology as a Gödelian universe, that topology which precludes the foliation of the universe by global time slices, the fact that our universe conforms to the same set of

[30] Confer Gödel 1949a.

[31] By the *foliation* of a universe is meant the defining in that universe of a sequence of time slices.

[32] The term "time slice" implies that the smooth spacelike hypersurface is global, so that the addition of the term "global" is not strictly necessary. I amend the term in this way for clarity, however, since it is feasible to define a local time slice in a Gödelian universe.

field equations as the Gödelian universes implies that our own universe should also be described in terms of a static block universe temporal metaphysics.

Gödel, like Putnam, appears to conceive of objectively distinguished present theories purely in terms of presentism, and the brief description of presentism which he gives suggests that he conceives of a presentist as a theorist who asserts that the existential status of the present moment is different to the existential status of past and future moments, in accordance with the description of presentism given in section 2 of the current chapter.

It is therefore presentism which Gödel's argument appears to be intended to preclude, rather than objectively distinguished present theories in general. However, just as Putnam's argument on the basis of special relativity would, if successful, preclude any objectively distinguished present theory even though it is aimed specifically at presentism, likewise an advocate of an objectively distinguished present theory other than presentism would not have any advantages over a presentist when it comes to giving an account of the temporal metaphysics of a Gödelian universe.

Any objectively distinguished present theory requires that global time slices be identifiable in a universe. One of these time slices can then constitute the objective correlate of what we experience as the present moment of time. A presentist will distinguish one time slice as the only existing time slice, constituting the present. A growing block universe theorist will distinguish some time slices as existing, constituting the past, one time slice as coming into existence, constituting the present, and time slices which do not yet exist as the future. A growing determinacy theorist will distinguish some time slices as determinate, constituting the past, one time slice as becoming determinate, constituting the present, and some time slices as indeterminate, constituting the future.

However, it is not possible to define any global time slices in a Gödelian universe so that such a universe simply cannot be described in terms of any of the objectively distinguished present theories.

As we will see, however, even though an objectively distinguished present account cannot be given of a Gödelian universe, it is not clear whether Gödel is entitled to deduce anything from this fact about the temporal metaphysics of the universe which we inhabit. In chapter 4, I will examine Steven Savitt's[33] assertion that Gödel needs to take a modal step in order to move from the conclusion that the temporal metaphysics of a Gödelian universe can only be described in static block universe terms to the conclusion that the temporal metaphysics of our universe can only be described in static block universe terms. I therefore consider in chapter 4 whether such a step can be justified.

(c) Thermodynamics As A Source Of Temporal Metaphysics

In considering Gödel's argument for a static block universe temporal metaphysics on the basis of general relativity, I noted that he modelled his Gödelian universes purely on the basis of Einstein's field equations. It emerges in Gödel's solutions to the field equations that an integral structural feature of a Gödelian universe is the *closed time-like curve.* A time-like curve in general is a curve through space-time such that if one moved along it, one would be moving through time rather than through space. A *closed* time-like curve is therefore a time-like curve such that if one moved along it, one would eventually arrive back at the same time at which one started.

As Albert Einstein[34] himself points out, however, in order to establish a temporal orientation on a closed time-like curve, or indeed on any time-like curve in a manifold modelled on the basis of general relativity, one needs to resort to theories of physics other than general relativity. Einstein suggests a method of establishing a temporal orientation on a closed time-like curve, a method based on signalling, which relies upon thermodynamic considerations.

In chapter 5, I examine Einstein's signalling technique and demonstrate that when the technique is applied to a closed time-like curve, a paradox ensues. The only way to avoid this paradox is to conclude that a single direction of time cannot be established all the way around a closed time-like curve. Since however the curve would no longer be time-like if a single direction of time could not be established all the way around it, this implies that a universe which is compatible with the second law of thermodynamics, upon which Einstein's signalling technique depends, cannot contain closed time-like curves. Given that closed time-like curves are an integral structural feature of Gödelian universes,[35] this implies that any universe which conforms to the second law of thermodynamics cannot be a Gödelian universe. If we assume that the universe which we inhabit conforms to the second law of thermodynamics, then we can deduce that our universe is not a Gödelian universe.

Gödel argued on the basis of general relativity that only a static block universe

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[33] Confer Savitt 1994.

[34] Confer Einstein 1949.

[35] Confer Malament 1985.

account can describe the temporal metaphysics of a Gödelian universe, given that such a universe does not admit foliation by global time slices. By extension, he wanted to claim that only a static block universe account can describe the temporal metaphysics of our universe, on the grounds that our universe is modelled by the same field equations as those used to model a Gödelian universe.

However, as already noted, a universe which conforms to the second law of thermodynamics cannot contain closed time-like curves and cannot therefore be a Gödelian universe. It therefore remains possible to foliate any universe which conforms to the second law of thermodynamics by global time-slices. Furthermore, it must be possible to define at least one objectively distinguished sequence of time slices in that universe, namely that sequence of time slices along which entropy increases.[36] A universe in which such a sequence can be defined is one of which an objectively distinct present account can in principle be given, since an objectively distinct present theorist can assert that one of the time slices in the sequence is objectively distinguished from the other time slices in the sequence. The time-slice so distinguished can then constitute the objective correlate of what we experience as the present moment.

Therefore, it turns out that Gödel's claim that an objectively distinct present account cannot be given of the temporal metaphysics of a Gödelian universe is only valid for universes which do not conform to the second law of thermodynamics. At best, Gödel is left claiming that our universe should only be described by a static block universe theory because it conforms to the same field equations as those to which Gödelian universes conform, a claim which involves a questionable modal step.

Although it is possible in principle to give an objectively distinct present account of the temporal metaphysics of any universe which conforms to the second law of thermodynamics, since it is possible to define a distinguished sequence of global time slices in such a universe, the question arises as to what would distinguish one of the time slices in the distinguished sequence from all of the other time slices in the distinguished sequence as the objective correlate of what we experience as the present moment.

The second law of thermodynamics states that the entropy of an isolated thermodynamic system inexorably increases over time. Some theorists have suggested, therefore, that increase in entropy might be the objective correlate of what we

[36] It is conceivable that entropy is increasing along more than one possible sequence of time slices, so that the conformity of a universe to the second law of thermodynamics does not necessarily tell us which foliation by global time slices we should choose.

experience as the passage of time.[37] However, the second law of thermodynamics does not provide us with any basis for distinguishing one time slice in a sequence of time slices from all the other time slices in that sequence, thereby allowing us to identify one time slice as the objective correlate of what we experience as the present moment.

As indicated previously, a presentist would claim that only one of the time slices in the sequence actually exists and that this is what defines it as the objective correlate of the present moment. A growing block universe theorist would claim that all those time slices in the sequence exist which constitute the objective correlates of past moments, whilst the time slice which is just coming into existence constitutes the objective correlate of the present moment. A growing determinacy theorist would claim that all the time slices in the sequence have the same existential status, but that those time slices which are determinate constitute the objective correlate of past moments, that time slice which is becoming determinate constitutes the objective correlate of the present moment, and those time slices which are indeterminate constitute the objective correlate of future moments. None of these positions emerge out of thermodynamic considerations.

Thus, whilst I observe in chapter 5 that a universe which conforms to the second law of thermodynamics is as compatible in principle with an objectively distinguished present temporal metaphysics as with a static block universe temporal metaphysics, I also observe that thermodynamic considerations do not imply an existential distinction between moments of time, nor any possible variation in the state of determinacy of moments of time. Thermodynamic considerations do not therefore help us to select between the static block universe and physically distinguished present accounts of temporal metaphysics.[38]

(d) Quantum Mechanics As A Source Of Temporal Metaphysics

In chapter 6, I examine an experiment in which quantum entities exhibit two types of behaviour, wave-like behaviour and particle-like behaviour. Consideration of this experiment suggests that the transition from wave-like behaviour to particle-like

[37] This suggestion embodies the assumption that the second law of thermodynamics is true in our universe.

[38] Thermodynamics might however suggest one way in which the physical status of locations in time could vary in a static block universe. If we were to associate an entropy with each location in time in a static block universe, then the increase in entropy specified by the second law of thermodynamics would imply that each location in time had a different entropy associated with it. Furthermore, locations in time ordered in terms of increasing entropy would, if the second law of thermodynamics is true, be ordered from earlier to later. Entropy could in that case serve as the physical property depicted in figure 1.2.

behaviour may be related to measurement, but it turns out that it is not easy to define what constitutes measurement of a quantum system. The way in which one conceives of measurement is found to depend upon how one interprets quantum mechanics, and I therefore examine a number of possible interpretations of quantum mechanics.

I then proceed to examine whether measurement invariably brings about an irreversible change in the state of a quantum system. I examine an argument formulated by Penrose[39] which suggests that quantum measurement does indeed bring about irreversible change. I also consider a paper by Aharanov, Bergmann and Lebowitz,[40] however, which throws the connection between quantum measurement and irreversibility into some doubt.

In chapter 7, I demonstrate that it is possible to devise a quantum mechanical equivalent to Einstein's signalling technique, provided that a measurement upon a quantum system is assumed to bring about an irreversible evolution in the behaviour of that system. I proceed to demonstrate that by applying the quantum mechanical equivalent of Einstein's signalling technique to a closed time-like curve of the type which occurs in a Gödelian universe, a similar paradox arises to that which arises when we apply Einstein's signalling technique to such a curve. The paradox implies that a single direction of time cannot be established all the way around a closed time-like curve, as did the paradox which arose from Einstein's signalling technique.

It emerges that we can identify at least one sequence of global time slices in any universe which conforms to the laws of quantum mechanics, provided that measurement of a quantum system brings about an irreversible evolution in that system. This result corresponds to the observation that we can identify at least one sequence of global time slices in any universe which conforms to the second law of thermodynamics. Universes in which measurement of quantum systems brings about irreversible evolution are therefore universes which are compatible in principle with an objectively distinguished present temporal metaphysics, for the same reason that universes which conform to the second law of thermodynamics are universes which are compatible in principle with an objectively distinguished present temporal metaphysics.

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[39] Confer Penrose 1989.
[40] Confer Aharanov, Bergmann and Lebowitz 1964.

5 The Aim Of The Analysis

The aim of the analysis in the following chapters is to indicate why caution must be exercised if one wishes to attempt to extract a temporal metaphysics from a theory of physics.

As we will see, a theory of physics may itself embody metaphysical assumptions which ultimately derive from the metaphysical beliefs of those physicists who formulated the theory. Thus a philosopher who treats a theory of physics as if it were devoid of metaphysical assumptions risks simply reproducing those assumptions which are embodied in the theory whilst attempting to formulate a temporal metaphysics on the basis of the theory.

It is already apparent that different theories of physics may imply different temporal metaphysics. Therefore, attempting to extract a temporal metaphysics from one theory of physics without considering other theories of physics cannot be justified. In the course of the analysis, it becomes apparent that a universe which conforms to the laws of thermodynamics and quantum mechanics, as well as the laws of special and general relativity, can be as readily described in objectively distinguished present terms as in static block universe terms. Therefore it turns out that, taken as a whole, our current laws of physics in no way constrain us to accept a particular temporal metaphysics as the temporal metaphysics of our universe.

Whilst the following analysis will imply certain methodological procedures which might constructively be employed if one wishes to attempt to establish one's temporal metaphysics on the basis of theories of physics, it will not be my aim to attempt to establish which temporal metaphysics constitutes the correct temporal metaphysics for our universe. Instead, the analysis will only go so far as to suggest that the theories of physics which we currently possess do not conclusively imply which temporal metaphysics we should adopt.

2

Special Relativity And The Relative Present

1 Introduction

A number of philosophers have looked to the special theory of relativity to guide them in constructing a metaphysics of time. Perhaps the best known paper is that by Hilary Putnam, entitled "Time And Physical Geometry" (Putnam 1967). The general structure of Putnam's paper is worth noting. He begins by describing a possible metaphysics of time, essentially an objectively distinguished present metaphysics of the presentist variety described in chapter 1, then goes on to show that this metaphysics is incompatible with a theory of physics, the special theory of relativity. He concludes that there is only one metaphysics of time available, namely that one which accords with the special theory of relativity. This metaphysics, which he believes we are compelled to accept, directly contradicts the metaphysics which he first described, and corresponds to a static block universe metaphysics. Two basic assumptions about special relativity underlie Putnam's argument: that there is only one metaphysics of time compatible with the theory, and that the theory itself is "correct" in a way that the posited presentist metaphysics was deemed not to be. The dependence is thus of metaphysics upon physics, although no theories of physics apart from special relativity are adduced in support of the argument.

We will see that the same structure of argument is employed by other philosophers who have examined the metaphysics of time, although the theory of physics chosen as the basis of the argument, and the philosophical conclusions drawn, vary. In this chapter, I will consider only arguments based upon special relativity. I will begin by considering Putnam's argument in detail, with reference also to the paper by

Rietdijk, "A Rigorous Proof Of Determinism Derived From The Special Theory Of Relativity" (Rietdijk 1966). In this paper, Rietdijk runs essentially the same argument as Putnam. Both Putnam and Rietdijk conclude that there is no difference in the existential status of "things" located in the past, present and future, a conclusion which is incompatible with presentist and growing block universe theories of temporal metaphysics, although not incompatible in principle with growing determinacy theories. However, the implication of the arguments employed by Putnam and Rietdjik that an objectively distinguished present cannot be identified in a universe conforming to the theory of special relativity would also rule out growing determinacy theories, if it turned out to be a valid implication.

Once I have examined the Putnam/Rietdijk argument, I will consider how the argument might be challenged. A paper by Maxwell, "Are Probabilism And Special Relativity Incompatible?" (Maxwell 1985), employs as its starting point the assumption that special relativity implies a static block universe metaphysics, but differs from the Putnam and Rietdijk papers in considering the compatibility of this metaphysics with other theories of physics, in particular quantum theory. I will conclude the current chapter with an appraisal of Maxwell's results, thereby providing a bridge between this chapter and chapter 6, where the implications of quantum theory for temporal metaphysics are considered in detail.

2 Putnam's Argument For The Equivalent Existential Status Of Things

In the paper "Time And Physical Geometry" (Putnam 1967), Putnam argues on the basis of special relativity that "things" in the past and future enjoy exactly the same existential status as "things" in the present. What exactly constitutes a thing is left open, though Putnam points out that the term "a thing" must be capable of referring to a thing in the past and future, as well as in the present. The metaphysics of time which Putnam believes is dictated by special relativity is compatible with a straightforward correspondence theory of meaning for the term "a thing", since things are deemed to exist in this metaphysics in the same way whether located in the past, present or future, relative to some observer. Such a straightforward theory is not available, however, to an objectively distinguished present theorist who equates existing with being present, that is, to a presentist. If a presentist refers to past or future "things", only things which do not exist (at the present moment) can be meant. A presentist, therefore, will require a more sophisticated theory of meaning for the term "a thing".

Putnam states three apparently uncontentious assumptions linking time with existential status, this status being couched in terms of whether or not a thing is real. Before considering Putnam's assumptions, therefore, let us consider his interpretation of what it is for a thing to be real. Putnam discusses towards the end of his paper the relationship between being real and existing, concluding that a thing is real if and only if it exists, in the tenseless sense of existence.

> "[T]he notion of being 'real' turns out to be coextensive with the *tenseless* notion of existence." (Putnam 1967, p.204)

For Putnam, therefore, the claim that things in the past and future are real is equivalent to the claim that they exist tenselessly.[1] This clearly accords with the temporal metaphysics which he concludes we are compelled to accept on the basis of special relativity. In a static block universe, (real) things exist (tenselessly) whether they are located in the past, present or future of some observer. So it is natural to conclude that a thing's being real is equivalent to its existing in some region of the space-time continuum.

But should a presentist assume the same equivalence between being real and existing tenselessly? Let us assume that presentism amounts to the claim that only things which are present exist. This removes the need for a tenseless sense of existence (at least in relation to things), since if something exists, by definition it exists "now". However, this need not amount to the claim that past and future things are not real. Indeed, the presentist may find a distinction between the statements "*X* is real" and "*X* exists" advantageous in defining what it is for a thing to be present, particularly in the light of the requirement for an explanation of meaningful reference to past and future things. The presentist could argue, for instance, that we can meaningfully refer to past and future things because they are real, even though they do not now exist.

Evidently, if the equivalence between being real and existing is maintained, then the presentist is barred from coherently claiming that past and future things are real, since only present things exist, and thus only present things are real. However, if the presentist *is* constrained to maintain an equivalence between being real and existing, the basis of such a constraint is not yet apparent. Therefore, in the analysis of Putnam's argument, an awareness of the possibility of distinguishing between being real and

[1] "Being real" is itself a tenseless concept for Putnam (e.g. "*all* future things <u>are</u> real" (Putnam 1967, p.204, my underline)) as a consequence of his argument.

existing tenselessly will be of assistance, even if the metaphysics of time to which Putnam concludes we are compelled has no use for such a distinction.[2]

The three assumptions on which Putnam bases his argument can be stated as follows. I have subdivided Putnam's second and third assumptions for clarity. The relation *R* which is employed in the assumptions is some relation between an observer and things such that things which stand in the relation *R* to an observer are real. For this reason, *R* is sometimes referred to as the reality relation. The possible candidates for *R* are discussed in more detail below.

(1) *I*-now am real.

(2.1) At least one other observer, *O*, is real.

(2.2) The observer *O* may be in motion relative to me.

(3.1) All and only the things which stand in the relation *R* to *I*-now are real.

(3.2) If *O*-now stands in the relation *R* to *I*-now, then all and only the things that stand in the relation *R* to *O*-now are real.

Putnam's first assumption echoes the Cartesian *cogito* and expresses the thought that a subject can with relative certainty assert its own reality. Note however that the assertion is temporally restricted to the present moment, an essential modification in the context of Putnam's argument. To assert temporally unrestricted reality of one's self would be to assume at least part of what Putnam is trying to prove.

The first part of the second assumption could be challenged by a solipsist, though such a challenge would not depend upon any temporal considerations. For any non-solipsist, (2.1) is uncontroversial, as is (2.2).

It is assumption (3) which contains the bulk of the temporal metaphysics, suggesting as it does that a thing's reality is related to its temporal status, whether it is past, present or future. It is the fact that, according to special relativity, a thing's temporal status is relative to an observer which leads Putnam to conclude that its reality cannot be dependent upon its temporal status, in effect to delete the phrase "and only" from (3.1) and (3.2). However, as Putnam indicates, the third assumption is vacuous

[2] A growing block universe theorist allows that present and past things exist and are real. This need not preclude future things from being real, even though they do not exist in a growing block universe. A growing determinacy theorist allows that past, present and future things exist and are real, since the objective difference between them is explained in terms of their state of determinacy in a growing determinacy universe. I have focussed upon the presentist position here, however, since Putnam is specifically arguing against presentism.

unless we allow that we can refer to things in the past and future, as well as in the present, whether or not we decide that they are real.

What is the relation *R*? Putnam, in an attempt not to prejudge the issue, suggests that it must be a physical relation independent of co-ordinate system and definable "tenselessly" in terms of fundamental physical notions. If we understand *R* as the relation "simultaneous with", then, in conjunction with (1), (3.1) can be interpreted as the belief that being simultaneous with *I*-now, what we would usually term "being present", is the necessary and sufficient condition for being real. This belief, which it is Putnam's aim to challenge, can also be expressed as the belief that past and future things, things which are not now present, are not real.

The assumption that *R* is the simultaneity relation creates no problems in classical physics. If I take *O*-now to be simultaneous with *I*-now, then things which are present (and therefore real) for *O*-now are also present (and therefore real) for *I*-now, even though they may not be directly observable by me (in which case I must rely on *O*'s report of their presentness). This relies on the assumption in classical physics that all observers share the same present, regardless of their location in the universe and their velocities relative to each other. However, treating *R* as the simultaneity relation is less innocuous when special relativity is assumed. By (2.2), *O* may be in motion relative to me. If *O*'s relative velocity is large, some sizable percentage of the speed of light, relativistic effects are significant.[3]

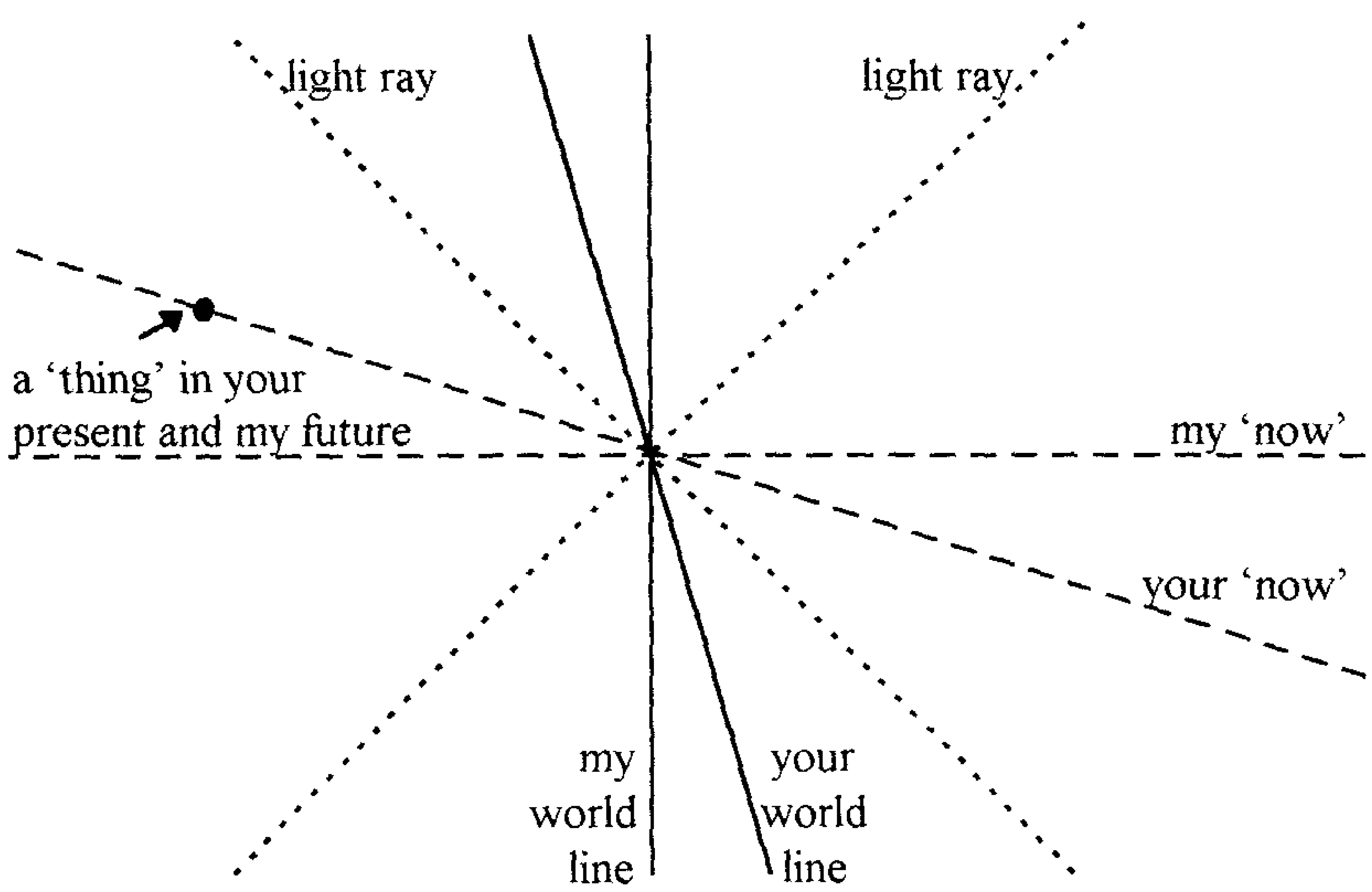

Fig. 2.1 Observers moving relative to one another experience different 'nows' in special relativity. Adapted from Putnam 1967, p.241.

[3] Relativistic effects exist where there is any velocity difference between two bodies, but for low velocity differentials such effects are so small as to be negligible for most purposes.

It is then the case, according to special relativity, that some things which are present for *O*-now (where "*O*-now" is *O* simultaneous with *I*-now) lie in *I*-now's future, as shown in figure 2.1.[4] But things which are present for *O*-now, that is, which stand in the relation *R* to *O*, are real by (3.2). Therefore, I must conclude that some things in my future are real just as all things in my present are real.

One argument against this conclusion can be quickly ruled out. We could insist that only those things simultaneous with *I*-now are real (i.e. interpret the relation *R* as "simultaneous with *I*-now"). Since the things simultaneous with *O*-now are not simultaneous with *I*-now, even though *O*-now is simultaneous with *I*-now, this version of *R* does not allow us to draw the conclusion that things in *I*-now's future, things simultaneous with *O*-now, are real. (It is worth noting the lack of transitivity evident in what *I*-now and *O*-now take to be present. From *I*-now's point of view, *O*-now is simultaneous with *I*-now. From *O*-now's point of view, however, *I*-now am not simultaneous with *O*-now. In fact, some future part of *I*-now ("*I*-later") is simultaneous with *O*-now, from *O*-now's point of view.)[5] The interpretation of *R* as the relation "simultaneous with *I*-now" is not permitted in the context of special relativity, however, since it contradicts the assumption that there are no privileged observers.[6] The suggested relation awards special status to *I*-now because if *I*-now experience a different present from *O*-now, it is my present which is deemed to define what is real.

Is it legitimate to interpret *R* as the relation "simultaneous with (any observer-now)", implying that what is real can be defined in relation to the present of *any* observer? Assumption (3.2), which gives rise to the conclusion that things in *I*-now's future have the same existential status as things in *I*-now's present, implies that if a thing is real for *O*-now, and *O*-now is real for *I*-now, then that thing is real for *I*-now. In other words, "being real for" is a transitive relation. However, we have already seen that, if we interpret *R* as a simultaneity relation, then *R* is not a reciprocal relation in Special Relativity. Thus, even if *O*-now is simultaneous with *I*-now (from *I*-now's point of view), it is not necessarily the case that *I*-now is simultaneous with *O*-now (from *O*-now's point of view). On the same basis, it can be seen that *R* interpreted as the

[4]A number of space-time diagrams appear in this chapter. These are two-dimensional representations of four-dimensional space-time. The convention of these diagrams is to represent time on the vertical axis, and (one-dimension of) space on the horizontal axis.

[5]See Rietdijk 1966, p.341. The point is not apparent from Putnam's diagram, but is discussed in detail in section 4 (a) below.

[6]This assumption is a fundamental tenet of special relativity, but not of general relativity. In the latter, a privileged observer may be chosen to be one whose velocity is the same as that of the average velocity of matter in the universe. Since special relativity neglects effects due to the existence of matter, there is no basis for establishing a privileged reference frame in the theory.

simultaneity relation is not transitive either. *O*-now may be calculated to be simultaneous with something which lies in *I*-now's future, whilst *I*-now is calculated to be simultaneous with *O*-now. Yet it is clearly not the case that *I*-now can be calculated to be simultaneous with the thing in its own future. So, if we do interpret R as the relation "simultaneous with (any observer-now)", we need to bear in mind that this is an intransitive relation, given special relativity, whilst "being real for" is transitive.

Putnam seems to suggest that the failure of transitivity if we interpret R as the relation "simultaneous with (any observer-now)" rules it out as the correct interpretation of R. Confusingly, he then neglects to say what he takes the correct interpretation of R to be. In fact, it makes sense to take R to be the relation "simultaneous with (any observer-now)", provided we acknowledge that being real for an observer is not *equivalent* to being simultaneous with that observer. In other words, it is possible for something to be real for an observer without being simultaneous with that observer. If R is interpreted as the simultaneity relation, however, assumptions (3.1) and (3.2) are contradictory, since all and only the things which are simultaneous with *I*-now are not all and only the things which are simultaneous with *O*-now. We need a reformulated assumption along the lines of the following.

(3*) All and only the things which stand in the relation R to *I*-now, *or* which stand in the relation R to *O*-now, where *O*-now stands in the relation R to *I*-now, are real.

It should be clear that the consequence of this assumption is that events in my (*I*-now's) future are real (confer figure 2.1). Putnam expresses a modified version of the third assumption as the claim that I should count as real every thing which bears the transitive closure of R to me: "i.e. which bears R to me, or which bears R to something that bears R to me, or which bears R to something that bears R to something that bears R to me, or...." (Putnam 1967, p.204).[7] If we consider just the two observers *I*-now and *O*-now, it can be shown that the range of things in *I*-now's future which are either present or past for *O*-now is limited by the fact that the maximum relative velocity difference between *I*-now and *O*-now is c, the speed of light.[8]

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[7] Observe that it does not matter if the relation R itself is not transitive when the condition for reality is formulated in this way, obviating the objection to the interpretation of R as the (intransitive) relation "simultaneous with (any observer-now)".

[8] One of the two fundamental axioms of special relativity is that the maximum relative velocity is c, the speed of light. Light is just one form of electromagnetic radiation, which also includes radio waves, x-rays and microwaves: all such radiation travels at c. The other axiom, alluded to in footnote 6, is that there are no privileged reference frames.

If reality were restricted only to things standing in first and second order *R*-relations to *I*-now, that is, to things which bear *R* to me, or which bear *R* to something that bears *R* to me, then the things in *I*-now's future would only be real up to a horizon defined by *O*-now's present when *O*-now is moving at *c* relative to *I*-now. Transitive closure of *R* (i.e. third order and higher *R*-relations) is required to ensure that *all* things in *I*-now's future are real. This raises the problem, which Putnam notes, of whether there will be enough future observers (future relative to *I*-now), since it is easy to envisage a future time during which no observers exist. The problem is overcome "if we allow all physical systems (even electromagnetic fields, etc.) as 'observers' ... and allow observers to use co-ordinate systems in which they are not at rest" (Putnam 1967, p.204). There is no obvious objection to this broad definition of what is to constitute an observer.

The argument on the basis of special relativity that "future" things enjoy the same reality status as "present" things (all temporal references relative to *I*-now) can be run for "past" things as well. Because the hypersurface, in this case hyperplane,[9] of simultaneity defined by *O*-now is "tilted" relative to the hyperplane defined by *I*-now, some things on *O*-now's hyperplane will lie in *I*-now's past, just as some of the things lie in *I*-now's future (confer figure 2.1). We can argue for the "identical to present" reality of these past things on the basis of their simultaneity with *O*-now (we are assuming as before that *O*-now is simultaneous with *I*-now).

As it stands, therefore, Putnam's argument from special relativity seems to offer a convincing basis for adopting a static block universe model of reality, with things in the past, present and future of any arbitrary observer enjoying the same reality status. There are, however, a number of problems with the argument. Before considering these, I want to examine an important consequence of adopting the static block universe model, a consequence which Putnam himself considers. When we come to examine the problems with Putnam's argument, it will be useful to remember that we can avoid (or lose, depending on one's point of view) this consequence by rejecting Putnam's conclusion.

[9] A hyperplane is the three dimensional equivalent of a two dimensional spatial plane In the context of special relativity, it is legitimate to speak about hyperplanes, since curvature of space-time does not occur in universes described purely in special relativistic terms. However, a simultaneity hyperplane has no invariant meaning in general relativity, where reference is made to hypersurfaces. Hyperplanes are a subset of hypersurfaces, where a hypersurface is the three dimensional equivalent of a two dimensional spatial surface. Hypersurfaces may or may not be curved, but if they are curved they are not hyperplanes.

3 The Relation Between Truth Values, Determinacy And Determinism

Consider the statement "There will be a sea battle tomorrow". According to Aristotle, this statement has no truth value, that is to say, there is no state of affairs[10] which it either correctly describes (in which case the statement would be true)[11] or incorrectly describes (in which case the statement would be false).[12] On the other hand, the statements "There was a sea battle yesterday" or "There is a sea battle happening now" do have truth values. To say that the statement "There is a sea battle happening now" is true is to say that the statement correctly describes some currently existing state of affairs. To say that it is false is to say that it does not correctly describe some currently existing state of affairs. Similarly, if the statement "There was a sea battle yesterday" is true, this indicates that a state of affairs existed[13] which corresponds to a sea battle.

Aristotle's denial that statements about future[14] states of affairs have truth values may stem from the fact that he takes future states of affairs to be at least partially undetermined: "not everything is or happens of necessity: some things happen as chance has it" (Aristotle, *De Interpretatione* 9). That is, he may consider that future states of affairs are indeterminate because they are not fully determined by the currently existing state of affairs. Whatever Aristotle's motivation for believing that future states are indeterminate, they contrast with past and present states of affairs which he takes to be determinate.

It is useful to clarify what it means to say that one state of affairs is determined by another state of affairs. Suppose that we use the proposition q to describe a future

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[10] So far only "things" have been introduced into the ontology. By a state of affairs is meant the particular arrangement and properties of a group of things at a particular time. For example, a sea battle at a particular moment consists of a group of ships and their crews arranged at sea, the ships then possessing certain properties such as being afloat, being on fire, and so on. In addition, an "event" can be defined as a change or group of changes in a state of affairs, that is, a change or group of changes in the arrangement and properties of things. Taken as a whole, a sea battle constitutes an event which can be defined as the various movements of the group of ships involved, together with the changes in the properties of those ships. Thus a ship may possess the property of being undamaged at the beginning of the battle, and possess the property of being damaged at the end. (Strictly, position itself is a property. The distinction between arrangement and other properties is made here solely for clarity.) It should be observed that both states of affairs and events are defined in terms of things. Following Prior 1968, I take things to be the basic component of my ontology. Confer the discussion of change in chapter 3, sections 3 and 4.

[11] Aristotle assumes a correspondence theory of truth.

[12] Confer Aristotle, *De Interpretatione* 9, ed. Ackrill 1987, pp. 17-19.

[13] It might, perhaps, be suggested that for statements about the past to have truth values, past states of affairs must exist tenselessly, that is, must exist in the same way as present states of affairs. This model would conflict with the presentism described by Putnam (in which only present things exist). However, the possibility of attaching a truth value to a statement about the past appears only to require that a state of affairs did once exist, rather than that it exists tenselessly. The attachment of a truth value does not necessarily imply that the state of affairs referred to exists now or exists tenselessly.

[14] Future, as always, defined relative to some observer.

state of affairs and the proposition p to describe the present state of affairs. To say that the future state of affairs q is determined by the present state of affairs p is to say that q is true as a description of a future moment, given the state of affairs described by p which obtains at the present moment. For example, if p is the proposition "Greece and Persia are at war and their naval fleets are assembled within a day's sailing of each other" and q is the proposition "There will be a sea battle tomorrow", then we might take q to be true given p, if we take it that the state of affairs described by p determines the state of affairs described by q.

David Lewis defines determinism in terms of possible worlds as follows.

> "A world is deterministic if every world with the same past and the same laws has the same future."

An alternative definition which avoids reference to possible worlds is as follows.

> "A world is deterministic if its past and its laws entail its future."[15]

To say that some future state of affairs is determinate, on the other hand, is to say that q is true or false as a description of some future moment. So if all future states of affairs are determinate, then the proposition "There will be a sea battle tomorrow" is either true or false.[16]

Aristotle's refusal to attach truth values to statements about the future can be interpreted as implying that he did not take future states of affairs to exist in the same way as present states of affairs. It is not coherent to assert that statements about the future do not have truth values, whilst allowing that (i) statements about the present do have truth values and (ii) future states of affairs exist in the same way as present states of affairs. Since Aristotle maintained (i), he must reject (ii). Note however that the claim that future states of affairs do not exist in the same way as present states of affairs is not the same as the claim that future states of affairs do not exist *simpliciter*.

On the assumption that future states of affairs are fundamentally different to past and present states of affairs, it is legitimate to deny that future states of affairs are

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[15] This reformulation of Lewis's definition was proposed by Keith Hossack. Confer Lewis 1986.
[16] Confer chapter 1, section 2(b)(iii).

determinate.[17] Aristotle's assumption that truth values can be attached to statements about the past, although it does not imply that past states of affairs exist in the same way as present ones (confer footnote 13), does imply that he takes it that only one past existed. To that extent, his view of the past resembles the one implicit in the metaphysics to which Putnam believes we are compelled by special relativity. Clearly, however, Aristotle's metaphysics is at odds with Putnam's because of his different position in relation to the status of future states of affairs.[18]

Let us compare Aristotle's claim that future states of affairs[19] are not determinate with Putnam's conclusion. For my future[20] to be indeterminate, it must be the case that, at this present moment, a proposition q describing the future is neither true nor false.

Present experience is never of contradictory states of affairs, however. Either there is a sea battle happening now, or there is not. From experience I deduce that, in my present, contradictory states of affairs cannot co-exist.[21] That is to say, the present is determinate. The proposition p proposed as a description of the present state of affairs is either true or false.

In the metaphysics envisaged by Putnam, the future exists in the same way as the present and past. The implication is that contradictory states of affairs cannot co-exist in the future (or past), and thus that there is only one possible way my future could be. Putnam's metaphysics, therefore, implies that the future is determinate. The proposition q proposed as a description of the future state of affairs is true or false.

It is important to observe, however, that Putnam describes Aristotle as an "indeterminist" (Putnam 1967) and does not appear to distinguish the claim that the future is indeterminate from the claim that the future is undetermined. Given that

[17] To be precise, Aristotle did not want to attach truth values to all statements about the future, only to some. His model is of a partially, not wholly, indeterminate future.

[18] Aristotle is essentially proposing what I have identified as a growing determinacy theory.

[19] I have moved from talking about things to talking about states of affairs. It might be objected that Putnam's argument was only about things, rather than states of affairs. However, any present experience is of a state of affairs, not simply of "things". Thus, my present experience is of a state of affairs. According to special relativity, someone may experience, in their present, things which are in my future. Once again, they must experience not simply the things but the arrangement and properties of those things, that is, the state of affairs which the things constitute. This state of affairs is in their present, my future, with all the consequent implications for its existential status. So the argument that future and past things have the same existential status as present things can be extended to future and past states of affairs. Hence the move from talking about things to talking about states of affairs is justified.

[20] One often sees expressions such as "the future (past, present) is determined" or "the future (past, present) is open". I take the expression "the future (past, present)" to be shorthand for "future (past, present) states of affairs", and use it as such.

[21] Whether this deduction is valid will have to be re-examined subsequently in the context of quantum mechanics. Confer chapters 6 and 7.

Putnam takes himself to be refuting Aristotle ("Aristotle was wrong" states Putnam), it may be that Putnam believes that his metaphysics implies determinism, rather than the determinacy of the future.

4 Problems With Putnam's Argument

There are a number of problems with Putnam's argument for a static block universe temporal metaphysics. He glides over the fact that two observers cannot coincide spatio-temporally, a fact which impacts on his argument. Furthermore, his argument employs the definition of simultaneity used in special relativity, a definition grounded upon the assumption that the speed of light is constant. We need to consider whether this assumption can be justified, and also whether there are any alternative methods of defining simultaneity which do not depend upon this assumption. We will then examine whether it is appropriate to equate a thing's reality with its simultaneity with *I*-now. Finally, we will acknowledge that the argument employed by Putnam and Rietdijk was already known by Kurt Gödel, some twenty years before they gave it full philosophical expression, and that he rejected it on the grounds that special relativity itself is of limited applicability in the type of universe we inhabit.

(a) Observers Never Coincide Spatio-Temporally

The diagram which Putnam uses to illustrate his argument (confer figure 2.1) shows "I" and "you" coinciding. The diagram in Rietdijk's 1966 paper is more accurate, since "I" (W_1) and "you"(W_2) are spatially separated.[22]

In Rietdijk's diagram, reproduced in simplified form in figure 2.2, W_1 is the first observer and W_2 is the second observer. W_2 is moving towards W_1 with constant velocity. W_1-now, the point A, is simultaneous with W_2-now, the point B, from the point of view of W_1, but W_2-now is simultaneous with the point P, some future stage of W_1, from the point of view of W_2.

Information from P, the point in W_1-now's future which W_2-now considers to be simultaneous, cannot reach W_2 before point L (since no signal can travel faster than the speed of light according to special relativity). Notice that, from W_1's point of view (as well as W_2's), when the light signal reaches W_2, P will be in W_1's past. If W_2 then sends a message to W_1, saying what happened at P, the message cannot reach W_1 before point

[22] The point which Putnam's diagram obscures is that physically distinct things cannot, by the definition of "distinct", occupy exactly the same space-time location.

M. Since, from both W_1's and W_2's point of view, *P* was already in W_1's past when the information from *P* reached W_2 at *L*, it must of course be in W_1's past when W_1 receives the information about *P* back from W_2.

In fact, no signal about some point in W_1's future from any other spatially separated observer can ever reach W_1 before that point in W_1's future becomes a point in W_1's past. Although this observation does not disprove Putnam's argument that an observer, with whom *I*-now consider myself simultaneous, may in turn consider himself simultaneous with some state of affairs in *I*-now's future, it does illustrate that no observer in my present is ever privy to information about my future. As we will see, this is significant in the context of the next problem with Putnam's argument.

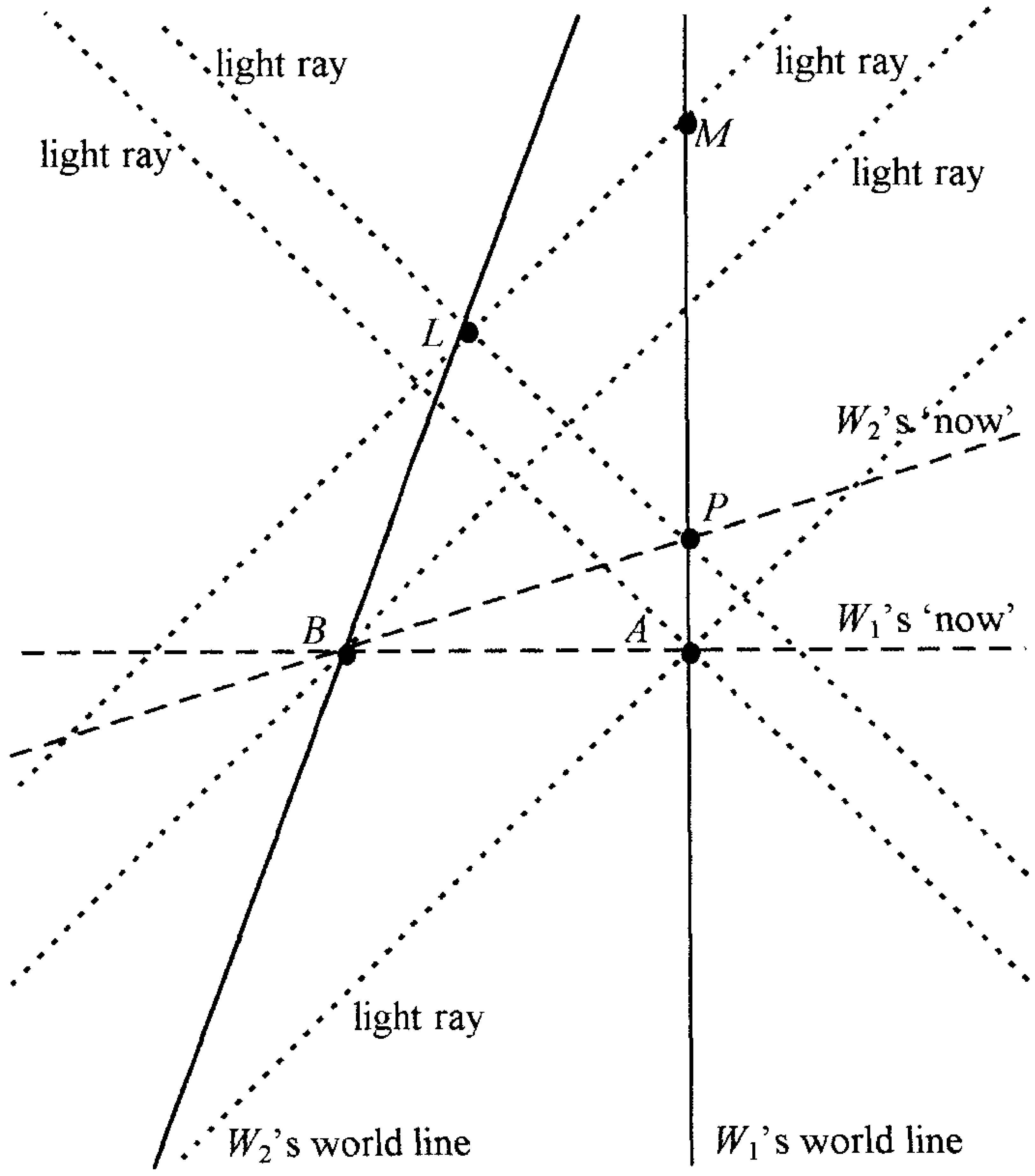

Fig. 2.2 Two spatially separated observers can only observe and communicate at speeds less than or equal to the speed of light. Adapted from Rietdijk 1966, p.341.

(b) The Conventionality Of Simultaneity

Putnam argues for the equivalent existential status of past, present and future on the grounds that everything simultaneous with *I*-now is real, and that some things simultaneous with *I*-now (moving at high velocity relative to *I*-now) are themselves simultaneous with things in *I*- now's future and *I*-now's past. The notion of simultaneity invoked by Putnam is that used by Einstein in formulating special relativity.

Simultaneous space-time points on the world-lines of two observers, E and E', who are stationary relative to one another, can be defined as follows. A light (or other electromagnetic) signal is sent at time t_0 from world-line E towards world-line E'. The space-time point at which the signal arrives at E' is termed B. The signal is then reflected back towards E, and arrives there at time t. The space-time point on E which is defined to be simultaneous with B is termed A. Both A and B are deemed to occur at time $(t-t_0)/2$ after the signal was sent from world-line E, from the point of view of an observer on the E world-line. This situation is illustrated in figure 2.3(a).

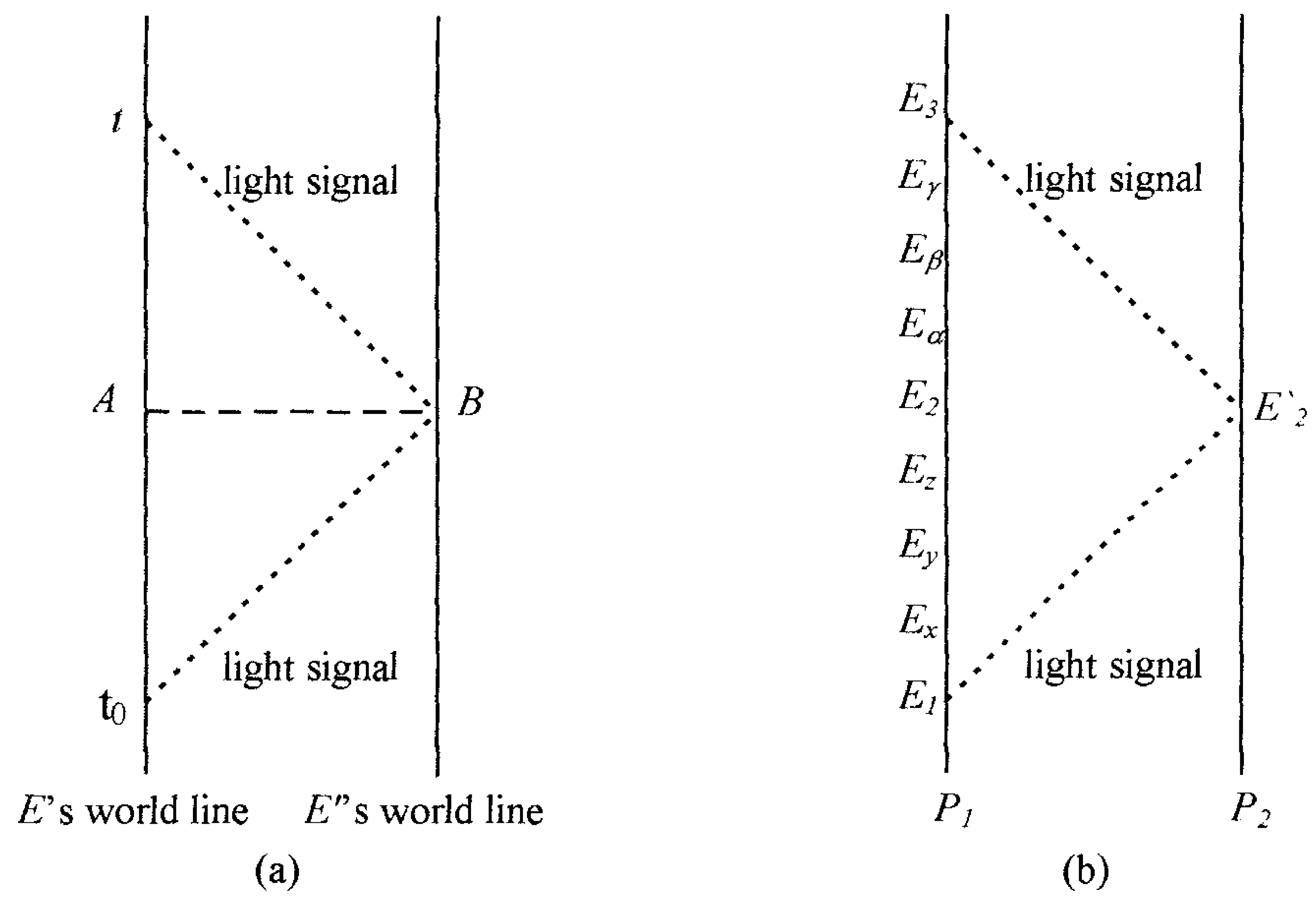

Fig: 2.3 (a) The construction of simultaneous space time points in special relativity. (b) Original diagram (slightly modified) from Grünbaum 1973, p.684, on which (a) is based.

When the observers are not stationary relative to one another, the world-line of one observer is no longer parallel to the other. An observer in one inertial frame will therefore disagree with an observer in another inertial frame as to which space-time point is simultaneous with which. This is the situation illustrated in figure 2.2, where W_1 considers A and B to be simultaneous, but W_2 considers B and P to be simultaneous. In order to understand how this situation comes about, it is helpful to employ a slightly different method of constructing two simultaneous space-time points. This method uses the same underlying assumptions as the method illustrated in figure 2.3(a), but makes use of two light signals, rather than one. In figure 2.4(a), a light signal is emitted from station B, and is deemed to arrive at the world-lines of stations A and C at the same time, from the point of view of the three stations and also from the point of view of a reference frame, stationary with respect to A, B and C, shown here as the x-t axes.

Space-time points A_1 and C_1 are therefore deemed to be simultaneous in the *x-t* axes reference frame. In figure 2.4(b), *A*, *B* and *C* all have a velocity with respect to the *x-t* axes reference frame. Thus, whilst *A* and *C* deem the light signal to arrive at their respective world-lines at the same time, from the point of view of the *x-t* axes reference frame the light signal reaches the world-line of *A* before it reaches the world-line of *C*. Thus the points A_1' and C_1' are simultaneous in the reference frame of the stations *A*, *B* and *C*, but consecutive in the *x-t* axes reference frame.

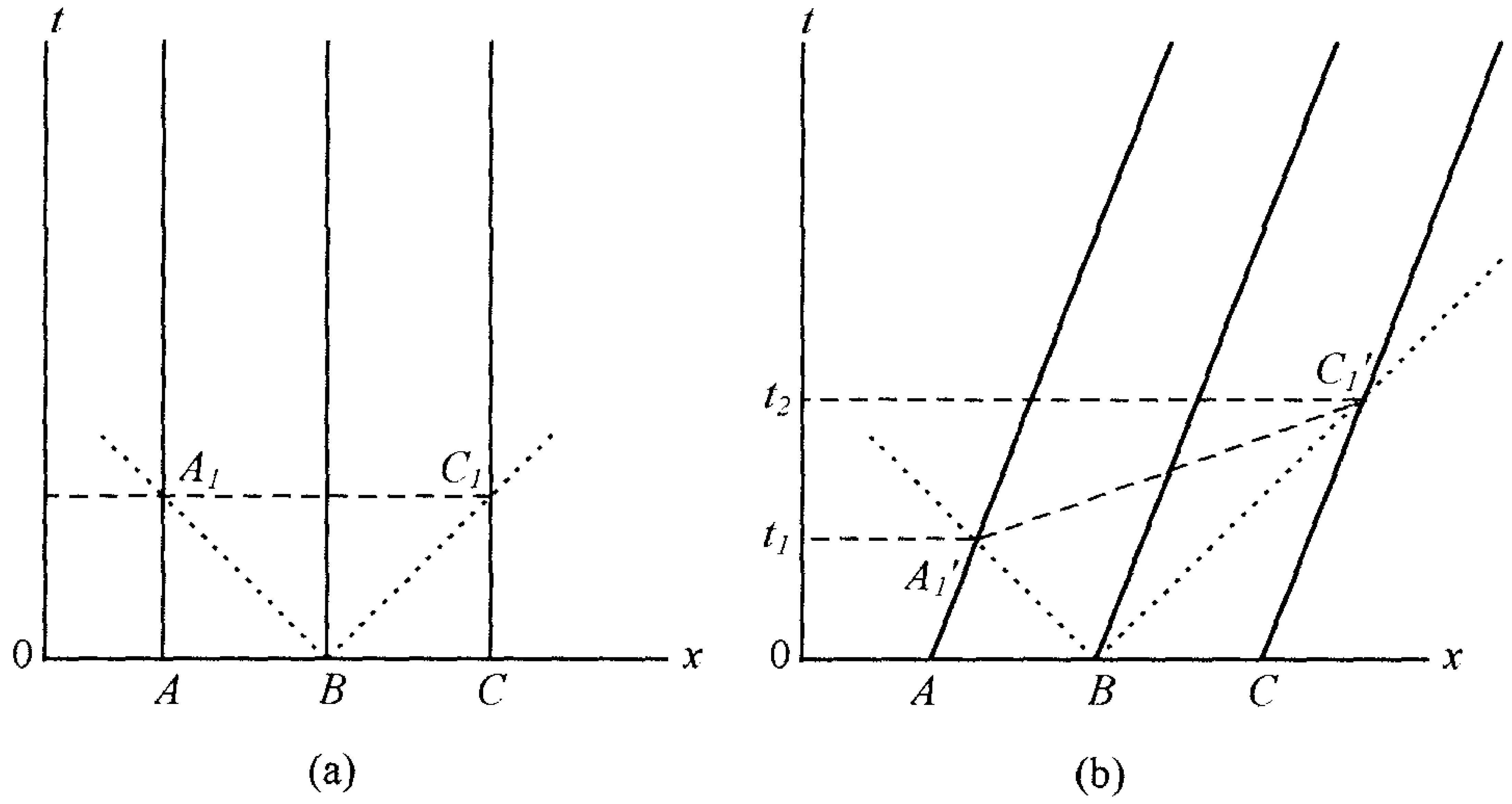

Fig. 2.4 (a) Space-time diagram showing experiment to define simultaneity at stations *A* and *C* (at rest in this reference frame) by light signals emitted from a station *B* midway between them. (b) Equivalent experiment for the case in which *A*, *B*, and *C* all have a velocity with respect to the reference frame. From French 1968, p.75.

The methods used to define simultaneous space-time points which we have been examining rest on the assumption that the speed of light is constant.[23] The speed of the light signal on the outward bound journey from *E* to *E'* in figure 2.3(a) is taken to be the same as the speed on the inward bound journey from *E'* to *E*. In that case, since the distance between *E* and *E'* remains constant, the time taken to complete each leg of the journey is the same. Hence we conclude that the signal reaches *E'* at the time $(t\text{-}t_0)/2$, and proceed to define the simultaneity of *A* and *B* on this basis. However, the assumption that the speed of light is constant cannot be independently confirmed, since the speed is just the distance divided by the time, and we do not know how long it takes the light ray to reach *E'* from *E*. All we have is an upper bound on the journey time from *E* to *E'* and back to *E*, which must take less than $(t\text{-}t_0)$.[24] As was mentioned earlier, the

[23] The speed of light to which I am referring is its speed in a vacuum (often represented as *c*). The speed of light varies in mediums, such as air or water.

[24] Confer Grünbaum 1973, pp.348-350.

constancy of the speed of light is one of the two fundamental axioms of special relativity, the other being that the laws of physics are the same in all inertial frames (see footnotes 7 and 9). However, despite the fact that the constancy of the speed of light is specified as an "axiom", there is no direct evidence for constancy of the speed of light beyond the definition of simultaneity given above.[25] As Grünbaum points out, "Einstein's philosophical supplanting of Newton's conception of simultaneity is *presupposed* by rather than first derived from his enunciation of the fundamental postulate of the constancy of the speed of light" (Grünbaum 1973, p.343). We see in figure 2.3(b) that a whole set of space-time points between t and t_0, E_x through to E_y, could be simultaneous with B if the speed of light varied on the outward and inward journeys. If in fact it is not the case that the speed of light is constant, then it is possible, at least in principle, to construct universes in which a single hyperplane of simultaneity, a universal present, is defined.

We proceed as follows. One inertial frame is defined to be "privileged", for example, one which is at rest relative to the centre of mass of the universe.[26] Suppose I am in this frame. Then I can define a hyperplane of simultaneity using one of the methods described above. Now suppose that you are in my hyperplane of simultaneity, and you are in motion relative to me. If you assume special relativity, you must assume that light always travels at the same speed for you as it does for me. Using the methods described above, you will calculate that you are simultaneous with things in my past or future. However, if in fact the speed of light can vary, it is possible that your plane of simultaneity is the same as mine, even though, by assuming the axioms of special relativity, you are misled into concluding that it is not. This is illustrated in figure 2.5.

If I (as the "privileged" observer) accept Putnam's assumption that everything simultaneous with *I*-now exists[27], I am entitled to assume that everything I am simultaneous with at this moment exists. However, since I am in the privileged inertial frame, I am further entitled to conclude that *only* those things *I* am simultaneous with exist. All those things which you (moving relative to me) calculate yourself to be simultaneous with on the basis of special relativity do not exist, since they do not lie in

[25] There is, however, experimental evidence which *suggests* that the speed of light must be constant. This is discussed later in this section.

[26] This may not be the most appropriate inertial frame to choose, and is suggested here simply as an example.

[27] Putnam's assumption is that everything simultaneous with *I*-now "is real" rather than that it "exists". Since, as indicated earlier, a presentist may not wish to deny that past and future things are real, but probably does wish to deny that they exist, I shall speak in terms of existence. I shall leave aside for now what a growing block universe theorist or a growing determinacy theorist might say. Confer footnote 2.

the simultaneity hyperplane defined in the privileged inertial frame. Thus a model of reality in which the speed of light varies is compatible with the presentist position since a single simultaneity hyperplane to which existence is restricted can be defined in this model.

Figure 2.6 illustrates the difference between the real and apparent simultaneity hyperplanes in a universe containing a privileged inertial frame in which the speed of light varies.

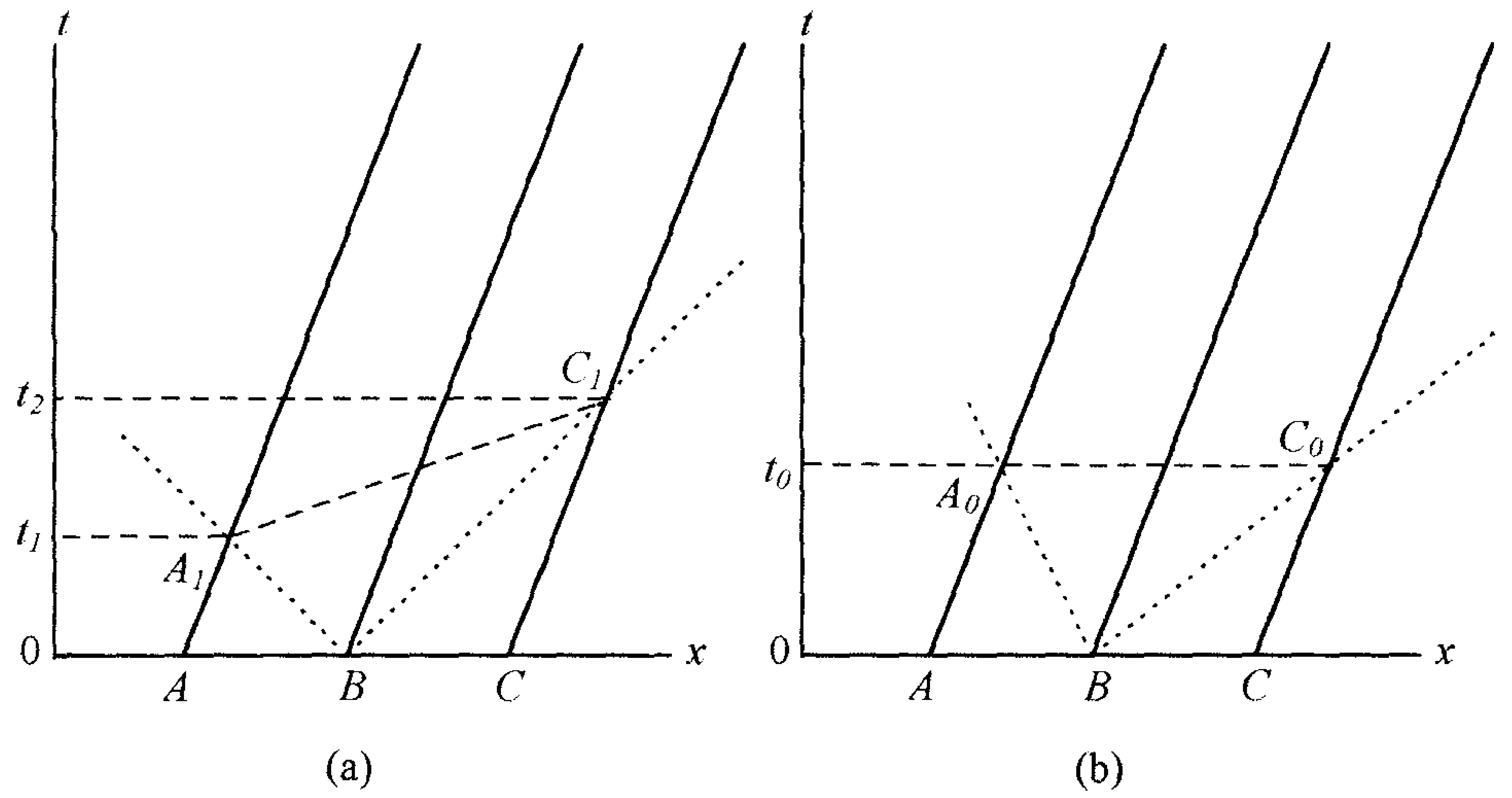

Fig. 2.5 (a) B, moving relative to the "privileged" inertial frame represented by the x-t axes, calculates A_1-C_1 as its simultaneity hyperplane or "present" by assuming that the velocity of light is constant. (b) If a simultaneity hyperplane A_0-C_0, in agreement with the "present" of the privileged inertial frame, is to be calculated light must travel faster than the velocity stated in special relativity from B to A_0, and slower than the velocity stated in special relativity from B to C_0.

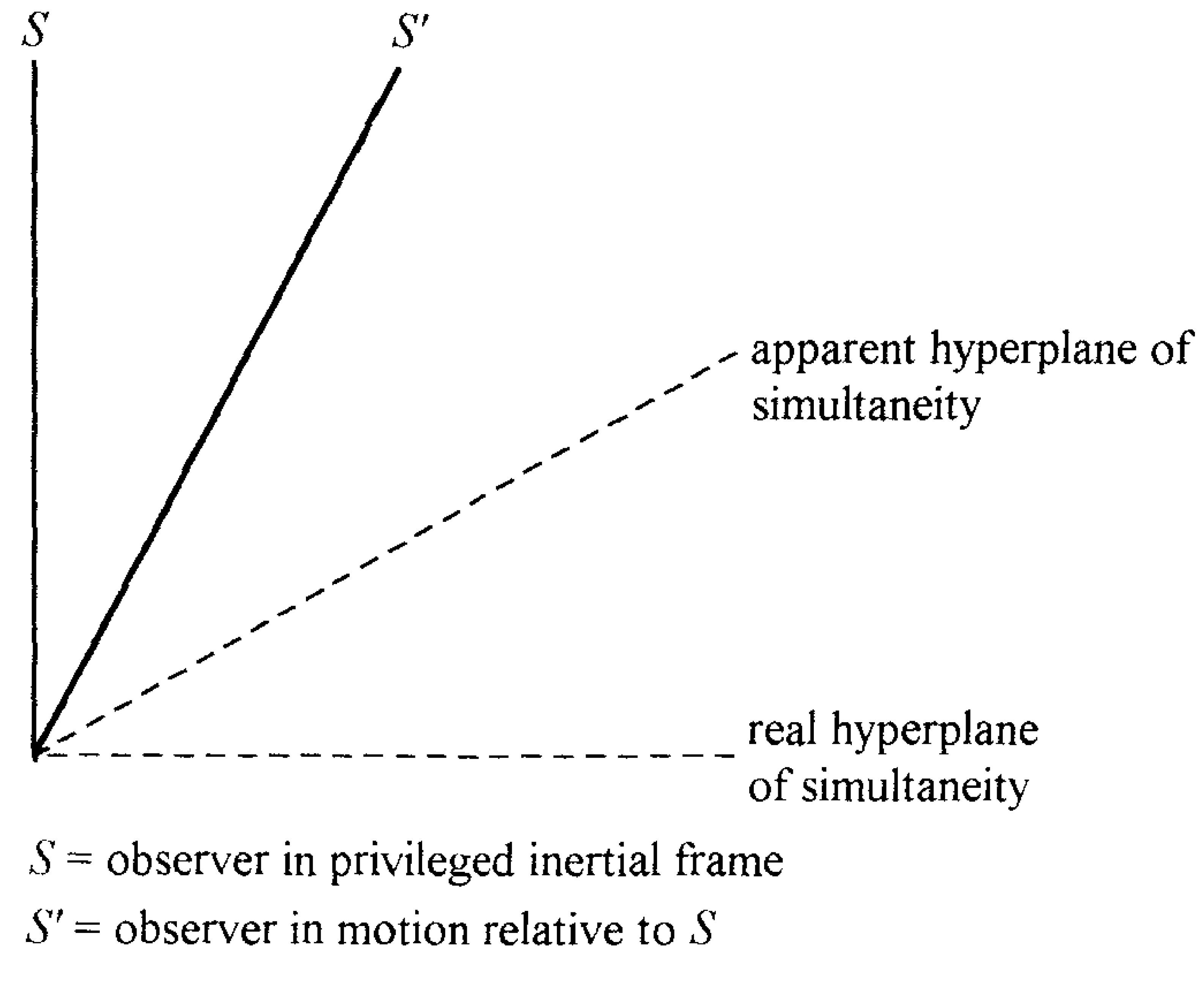

Fig. 2.6 The real and apparent simultaneity hyperplanes in a universe containing a privileged inertial frame in which the speed of light varies.

There are, however, some obvious objections to defining a privileged simultaneity hyperplane. The charge could be made that allowing the speed of light to vary in just such a way that a privileged hyperplane of simultaneity is defined is *ad hoc*. In the example depicted in figure 2.5(b), if the speed of light were to vary in any way other than the way illustrated, no such hyperplane could be defined. In order to refute the charge that the allowed variation in the speed of light is *ad hoc*, it would be necessary to explain what is causing the speed of light to vary. However, someone wishing to defend a presentist position could retort that the assumption that distance and time vary in just such a way that the speed of light remains constant (as is the case in special relativity) is equally *ad hoc*, and equally unexplained. It could be argued that we must start with the consequences of our assumptions, and work back from them to determine which assumptions are the correct ones, on the basis that the assumptions themselves are not empirically determined. Thus if we find that the consequence of assuming that the speed of light is constant in all inertial frames is that past and future things can be shown to exist in the same way as present things, this may lead presentists to conclude that the speed of light is not in fact constant.[28]

However, a further objection to defining a privileged simultaneity hyperplane is that the "assumption" that the speed of light is constant can, in fact, be shown to be true by empirical means. If this were the case, it would preclude the attempt to retrieve a privileged simultaneity hyperplane by allowing the speed of light to vary. In relation to this objection, we may recall the search in the nineteenth century for "the aether". This search arose out of the assumption that light, like sound, must be mechanically propagated through a medium. The suggested medium was the aether, a substance so tenuous as to be invisible to almost all attempts to detect it. Nonetheless, it was suggested that, if the aether did exist, some effects of its existence should be apparent. In particular, it was proposed that the aether would affect the speed of light travelling through it. Numerous physics experiments were carried out towards the end of the nineteenth century to try to prove the existence of the aether, without success. Indeed, Einstein cites the failure of these experiments as a motivating factor in his formulation

[28] Here we may recall the demonstration in the previous section that, even assuming special relativity, no observer in my present is ever privy to information about my future. There is thus no observational evidence for the claim that an observer could be simultaneous with things in my future. Consequently, assuming that the speed of light is not constant would have no observational repercussions.

of the theory of relativity.[29] Some advocates of special relativity have argued that the results of these and subsequent experiments to detect the existence of the aether should be interpreted as empirical evidence that the speed of light is constant.

> "Einstein's second postulate, on the universality of c, was a dramatic innovation. It was framed in a way that would seem to deny the possibility of any independent experimental check. It has been argued, however, that this essential feature of special relativity can in fact be based on observational evidence." (French 1968, p.72)

The observational evidence referred to is the results of aether detection experiments. Thus the "null result" of the Michelson-Morley experiment, one of the most famous attempts to detect the aether, "is consistent with the proposition that the speed of light is the same in all directions with respect to a reference frame having some arbitrary (but unknown) motion through space" (French 1968, p.73). However, evidence which is consistent with a constant speed of light is not proof of that constancy, and this criticism can be made of all the results of the aether experiments. None of the results prove that the speed of light is *not* constant (hence none of them provide evidence for the existence of aether). On the other hand, none of them prove that the speed of light *is* constant. As stated earlier, the assumption that the speed of light is constant cannot be independently confirmed, since the speed is just the distance divided by the time, and we do not know at what time relative to one world line a light signal reaches another world line.

With reference to figure 2.3(a), it might appear that E' could simply record on a clock the time at which the light signal reached the E' world line, and then show the clock to E. The problem with this is that we cannot be entirely sure how the time displayed on a clock from the E' world line relates to the time displayed on a clock from the E world line. Even if we initially synchronize two clocks on the E world line, we are still required to move one of the clocks to the E' world line, and then to move it back again after the light signal has been detected in order to compare the readings on the two clocks. Even if the two clocks remain synchronized when they are brought back together, we still cannot be sure that a time recorded on the clock on the E' world line is simultaneous with the "same" time on the clock on the E world line. It is possible that,

[29] According to Zahar (1989), however, the failure of the aether detection experiments was probably not the factor which originally motivated Einstein to formulate his theory of relativity.

as a result of moving the clock from the E world line to the E' world line, a time reading of t_1 on the clock on the E' world line corresponds to a time reading of $t_1 \pm \Delta t$ on the clock on the E world line. This time difference is then alleviated when the clock is moved back from the E' world line to the E world line, disguising the fact that the time recorded on the E' world line for the detection of the light signal does not correspond to the "same" time on the E world line. Why might we consider it possible for a clock to behave in such a fashion? In order to move a clock from the E world line to the E' world line and back again, we need to exert a force on it. We cannot be sure whether two synchronized clocks will remain synchronized when a force is exerted on one of them and not on the other.

As a consequence, we are not entitled to conclude that the time recorded on a clock can be cited as the time taken for a light signal to travel from one world line to another. Therefore, all we can do is assume the constancy of the speed of light. The aether detection experiments, by their very nature, are incapable of proving or disproving this hypothesis.

As we have seen, the objections against the possibility that the speed of light varies are not insurmountable.[30] The criticism of Putnam's argument, therefore, is not that there is conclusive evidence that the speed of light does in fact vary, nor that a privileged simultaneity hyperplane can be defined as a consequence, but rather that the assumptions to the contrary, fundamental as they are to his argument, are themselves metaphysical assumptions.

(c) Defining Simultaneity By Non-Relativistic Means

As we saw in the previous section, Putnam employs the definition of simultaneity, used by Einstein in formulating special relativity, in his argument for the equivalent existential status of past, present and future. It was shown that this definition is conventional, based upon the assumption that the speed of light is constant, an assumption which does not appear to be empirically verifiable. It is useful therefore to consider whether simultaneity could be defined in a way which does not rest upon an assumption about the speed of light.

Suppose that some form of signal could be sent at an infinite speed. That is, suppose that a signal could be sent which would be detected by an observer, spatially

[30] The proposal that the aether might affect the speed of light traveling through it could provide the basis of an explanation for *why* the speed varies, if it does, thereby refuting the charge that the allowed variation in the speed of light is *ad hoc*.

separated from the sender by some arbitrary distance, at the *same* moment of time that the signal was sent. An alternative way of imagining an infinite speed signal is to imagine a signal with zero transmission time between sender and detector. In the case of such a signal, if A sends the signal at the moment A_0, and B receives the signal at the moment B_0, then both A and B could be sure that A_0 and B_0 were simultaneous, provided of course that they knew that the signal had infinite speed. The simultaneity of A_0 and B_0 would be guaranteed, no matter how far apart A and B were when the signal was transmitted, or what their relative velocity was.[31] This is the situation illustrated in figure 2.7.

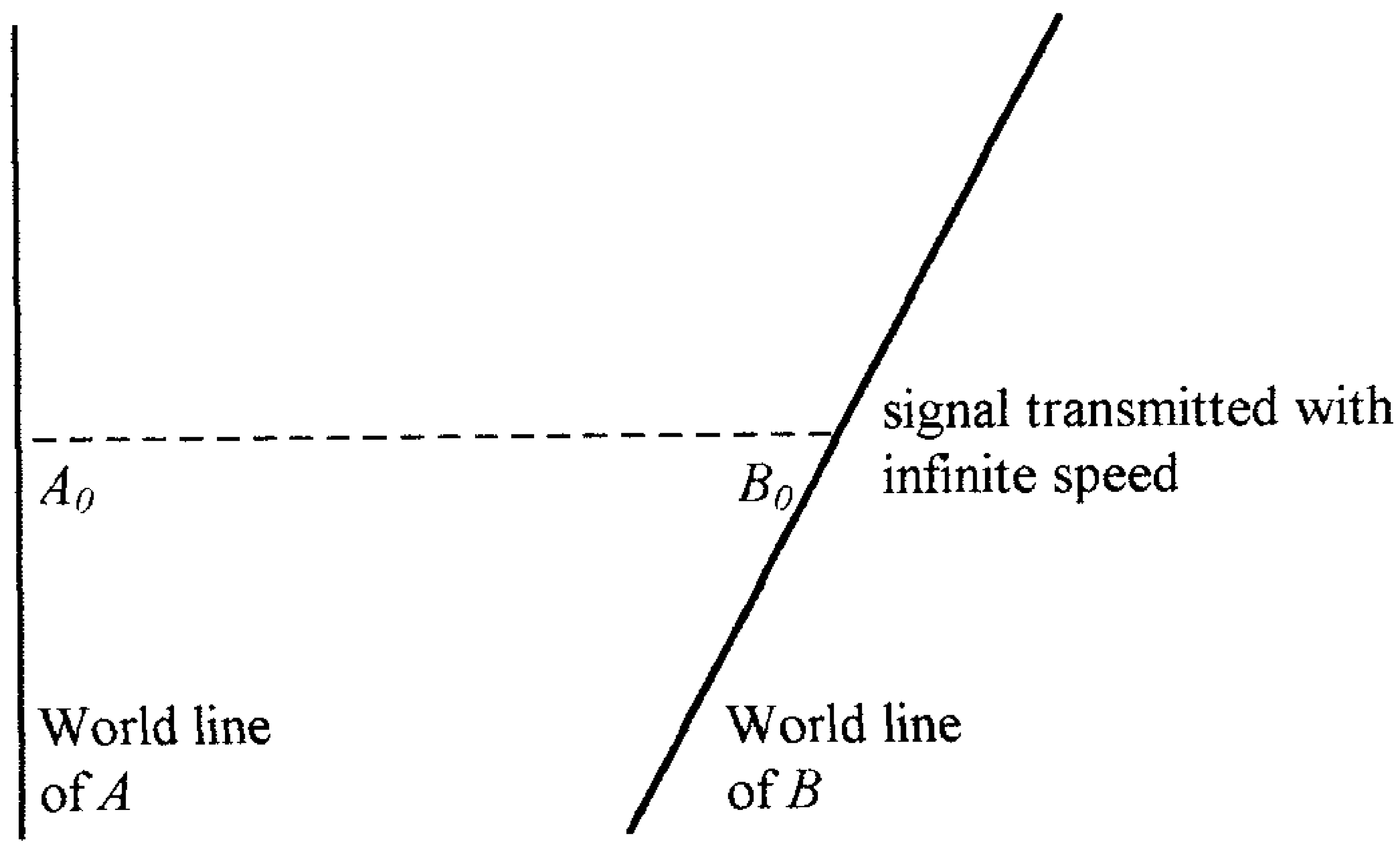

Fig. 2.7 A and B can be sure that A_0 and B_0 are simultaneous space-time points if a signal is transmitted at infinite speed between their respective world lines, even if B is moving relative to A, the situation illustrated here.

Clearly an infinite speed signal allows us to define a privileged simultaneity hyperplane. An observer detecting an infinite speed signal can be sure that the detection of the signal is simultaneous with the transmission of the signal by its sender, regardless of what inertial frame either the sender or the observer occupy. Furthermore, the observer can be sure that any other observer detecting the signal detects it at exactly the same time as he does. The observer can therefore agree on a single simultaneity hyperplane with the sender, and also with any other observer of the signal, namely the hyperplane in which the sending and detection of the signal takes place. If then we accept Putnam's

[31] Special relativity implies that the signal could not be an electromagnetic signal since one of the fundamental tenets of the theory is that c, the velocity of electromagnetic signals, is the maximum possible relative velocity. Given that c is not infinite, an electromagnetic signal will always take a length of time greater than zero to travel from its point of transmission to its point of reception. The method examined in this section does not assume special relativity, so it does not *assert* that the infinite velocity signal could not be an electromagnetic signal. It does not, however, appear likely that an infinite velocity signal could be electromagnetic, given the experimental evidence available.

assumption that any thing simultaneous with *I*-now is real, then every observer receiving an infinite speed signal from *I*-now would know that all observers of the signal, plus *I*-now, agree on a simultaneity hyperplane, and therefore agree on what things are real, namely all things falling within that hyperplane. Putnam's argument for the equivalent existential status of past, present and future can no longer be run in the context of infinite speed signalling, since all observers would define the privileged simultaneity hyperplane as their present. No observer would consider this hyperplane to be in his future or past, so we would not be in a position to deduce the existential status of the future or past, at least not in the way that Putnam does.

If infinite speed signalling is possible, therefore, it would offer an alternative method of defining simultaneity which is not susceptible to the type of argument which Putnam runs. It is, therefore, more attractive to a presentist who wishes to avoid the conclusion reached by Putnam that past, present and future states of affairs enjoy the same existential status. However, if infinite speed signalling is physically impossible (it is evidently not logically impossible), as special relativity would seem to suggest, then a presentist is denied this means of evading Putnam's conclusion.

In fact, although the possibility of infinite speed signalling remains speculative, there are some aspects of physical theory which may be construed as implying its physical possibility. The existence of particles which travel faster than the speed of light, commonly termed tachyons, has been posited by some physicists.[32] These particles occur as theoretical components of quantum field theory and many versions of string theory. Although they are theoretical in the sense that we have no evidence of their existence, if such particles existed they might offer the possibility of infinite speed signalling, or at least signalling faster than the speed of light.

The existence of such particles would, however, raise causal problems. If a tachyon could interact with a "tardyon" (any particle travelling at less than the speed of light), then a tardyon could, in theory, communicate with its past via the tachyon. Although we usually interpret causation as occurring from the past into the future, the existence of tachyons would raise the possibility of causation from the future into the past. This might be seen as an argument against the possibility of tachyons, or alternatively it might be seen as a challenge to our belief that causation is always from past to future.

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[32] The Indian physicist George Sudarshan and German physicist Arnold Sommerfeld are taken to be the first physicists to give a theoretical description of tachyons.

The possibility of defining a privileged simultaneity hyperplane also emerges in another context. Experiments have been performed by physicists[33] which exhibit some of the features we might expect of infinite speed signalling. In these experiments, the interaction of some apparatus, *O*, with one entity, *A*, modifies the behaviour of another, spatially separated, entity *B*. The modification of *B*'s behaviour as a consequence of the interaction of *O* with *A* occurs faster than a light signal could travel between *A* and *B*, and appears to be instantaneous. If we define *B*'s change of behaviour as a consequence of a "signal" from *A*, then that signal has infinite speed.

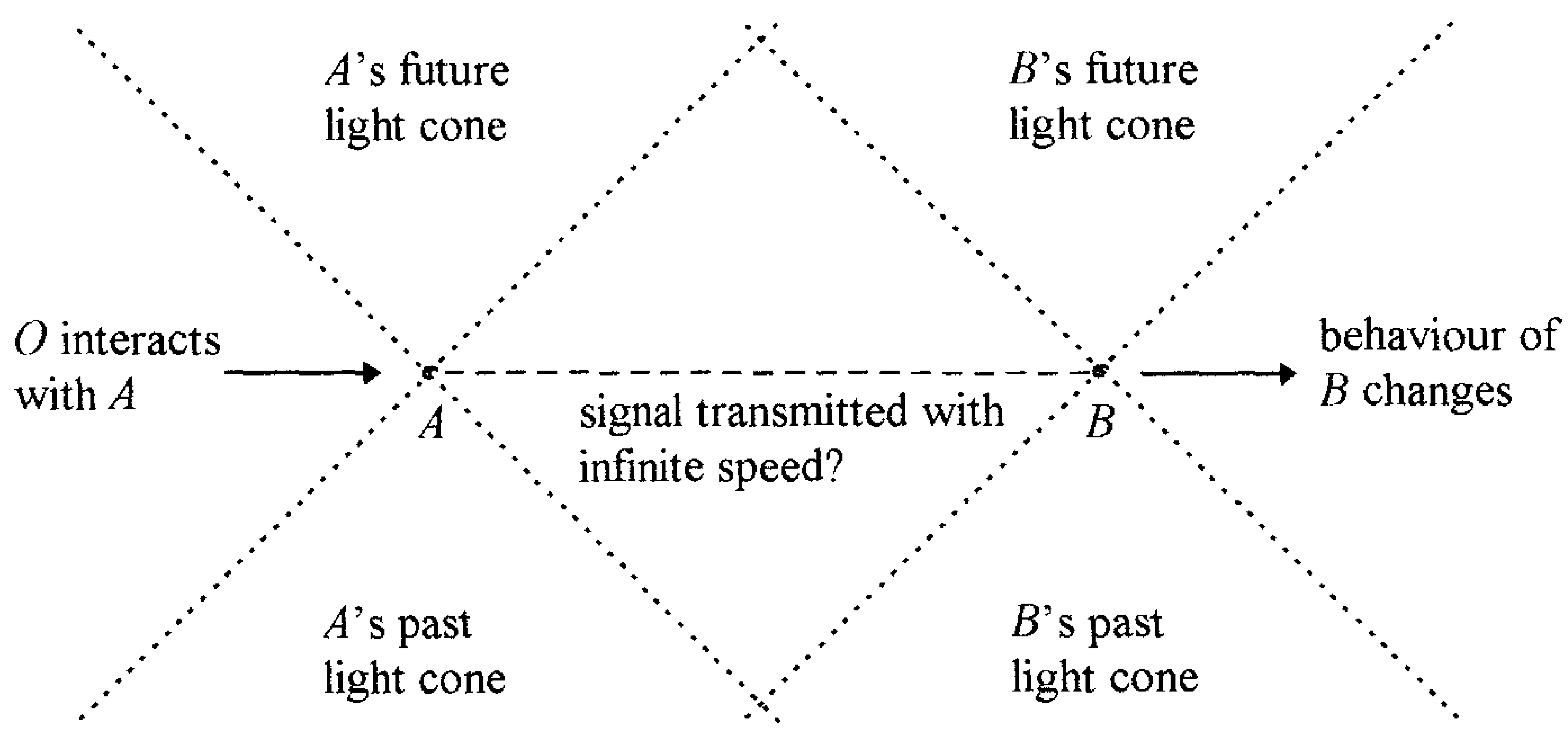

Fig. 2.8 In some experimental situations, it is observed that interaction of *O* with *A* appears to produce an instantaneous change of behaviour in spatially separated *B*. This may provide a non-relativistic basis for defining simultaneity. (*A*'s and *B*'s light cones are shown, to emphasise that any "communication" between them is faster than light).

Could the type of behaviour observed in these experiments constitute infinite speed signalling? It has been pointed out[34] that messages could not be transmitted by this means, since the state of *A* prior to its interaction with the apparatus *O*, and consequently its state after the interaction, is not predictable. Although the behaviour of the spatially separated entity *B* is changed by the interaction of *A* with *O*, the person operating *O* cannot determine the result of the interaction with *A*, and consequently cannot determine how the behaviour of *B* will be changed. The changes in behaviour of *B* will therefore be random[35], although correlated to the changes in behaviour of *A* (which are themselves random). To this extent, it can be argued that the experimental

[33] The experiments were devised to test Einstein's principle of separability, his assertion that interaction with one entity could not influence the behaviour of any entity not in the future light cone of the first entity. The results of these so-called EPR experiments, named after the paper written by Einstein, Podolsky and Rosen (1935), are not as clear cut as they are sometimes taken to be, as Redhead (1989) illustrates.

[34] For example, by Gribbin 1984, p.228.

[35] At least, they appear to be random, on the basis of our knowledge of the system.

results do not contradict special relativity, since the observed behaviour of the spatially separated entities does not provide a means of sending messages faster than light. Nonetheless, what the experiments do seem to indicate is that we can define a single hyperplane of simultaneity for *A* and *B*. The interaction of *O* with *A*, occurring as it must in *A*'s present, changes *B*'s behaviour in *B*'s present.[36] Therefore *A* and *B* share the same present, and this is the case even if they are far apart in space. Furthermore, *A* and *B* are in motion relative to each other, and therefore inhabit different inertial frames. According to Putnam's reasoning, they should therefore define different simultaneity hyperplanes. The fact that it appears incorrect to assert that they do so undermines Putnam's argument, and indeed poses a challenge to the definition of simultaneity which underpins special relativity.[37]

It is worth observing that the possibility of instantaneous interaction between spatially separated particles is perhaps slightly less problematic in causal terms than the possible existence of tachyons. If the instantaneous interaction of two particles implies a privileged simultaneity hyperplane, then if we deem their interaction to be causal at all, it is a case of instantaneous causation rather than backward causation through time. Although instantaneous causation evidently conflicts with the assumption that cause precedes effect, it is perhaps misleading to think of an instantaneous interaction in causal terms anyway. How precisely we should conceive of instantaneous interaction in that case remains to be seen..

I have introduced the issue of instantaneous interaction here because if such an interaction can occur, then we can meaningfully conceive of a simultaneity hyperplane between spatially separated things which does not rely upon the relativistic definition of simultaneity, implying further caution before accepting Putnam's argument for the equivalent existential status of past, present and future. The possibility of such an interaction remains highly speculative, however.

(d) Challenging The Equation Of Reality With Simultaneity

We have, up to now, been accepting Putnam's assumption that all the things which are simultaneous with *I*-now are real. However, it has been proposed by Stein (1991) that using this assumption to formulate one's criterion of reality is unjustified.[38] The "reality

[36] Note the assumption implicit in this statement, that neither an interaction nor a change of behaviour can occur in an entity's past or future The assumption is justified by observing that implicit in our concept of "present" is the idea that this is the moment of time in which interaction and change occurs.

[37] Tooley 1997 offers a very similar argument in his chapter on special relativity.

[38] We should recall that a presentist may wish to maintain a distinction between being real and existing.

relation", which Putnam terms R, is not simultaneity by default. Stein, in a response to Maxwell's discussion of Putnam's argument[39], which is also intended as a criticism of Rietdijk's (1966) and Putnam's (1967) original argument, argues that special relativity is not, contrary to the conclusion of RPM[40], *a priori* incompatible with a presentist model in which the existential status of the present is different from the existential status of the past and future. Stein argues that it is possible to choose a reality relation within special relativity which is compatible with presentism.[41] He envisages a presentist metaphysics in which the past is regarded as "ontologically fixed and definite" (he quotes the phrase from Maxwell) and the future is "not yet settled", and suggests four basic principles which must be observed.[42]

(i) The distinction between "definite" (past) and "unsettled" (future) must be made relative to the fundamental entity, the point here and now.[43]

(ii) If the state at point b is already definite as of point a, then everything already definite as of b is already definite as of a. That is, "is already definite as of" is a transitive relation between points.

(iii) The state at any point a is already definite as of a itself. That is, "is already definite as of" is a reflexive relation.

(iv) For any point a, there are points whose state is still unsettled as of a.

Of these principles, (i) and (iv) embody an objectively distinguished present metaphysics, and would clearly be disputed by supporters of a static block universe metaphysics. However, according to Stein, these principles are to be accepted or rejected *prior* to the selection of the reality relation, and assist in determining which

Strictly, the assumption which Putnam makes is that all the things which are simultaneous with I-now *exist*. On the basis of Putnam's conclusion, however, existing (tenselessly) is equivalent to being real. This subtlety is not considered by Stein (see below) who therefore treats the relation R as a criterion of reality, rather than existence.

[39] Maxwell's 1985 paper is discussed in detail in section 3.5 below.

[40] Clifton and Hogarth (1995) introduce the abbreviation RPM for Rietdijk, Putnam and Maxwell since they all employ essentially the same argument based on the theory of special relativity. I shall use this abbreviation henceforth.

[41] In fact, it is not clear that Stein's proposed reality relation is compatible with presentism. As we will see, his reality relation seems to imply a universe more like that of a growing block universe theorist or a growing determinacy theorist.

[42] I have paraphrased Stein's four basic principles in order to clarify them. Confer Stein 1991, p.148.

relation is appropriate. The structure of Stein's argument suggests that the choice of reality relation may be determined *by* the metaphysics, rather than the metaphysics being determined by the reality relation.

Although we have seen how the static block universe metaphysics follows from RPM's choice of simultaneity as the reality relation, the fact that simultaneity apparently entails a static block universe metaphysics could be viewed (and apparently is viewed by Stein) as the determining factor in the choice of simultaneity as the reality relation in the first place. This observation would carry additional weight if it could be shown that other viable reality relations can be formulated which do not entail a static block universe metaphysics.

However, whilst Stein is suspicious of RPM's choice of simultaneity as the reality relation, on the grounds that this reality relation apparently entails a static block universe metaphysics in the context of special relativity, it should be noted that the assumption of simultaneity as the reality relation embodies what appears to be a central tenet of presentism, namely that if x exists now, then x and everything that is simultaneous with x is real. To criticise RPM for choosing simultaneity as their reality relation is to overlook the fact that this is precisely the reality relation adopted by most presentists.[44]

Nonetheless, Stein believes that it is possible to formulate an alternative reality relation, one acceptable to presentists, but one which does not have the consequence in the context of special relativity of precluding presentism. Stein is careful to ensure that his reality relation is compatible with special relativity, observing that, for it to be "definable in terms of the geometric structure" (of special relativity), it "must be invariant with respect to all automorphisms of that structure" (Stein 1991, p.149). However, whilst attending to the essentially mathematical requirement of invariance, Stein suggests that a certain amount of interpretation of special relativity is required. He assumes that the Einstein-Minkowski (that is, special relativistic) structure, which provides the geometry in terms of which the reality relation is to be defined, is spatio-temporal. This assumption would be accepted by static block universe theorists, as well as presentists, as the standard interpretation of special relativity.

However, Stein contends that we must in addition assume that the structure is time-oriented, that is, we must assume in effect that one region of the space-time structure ("the past") is distinguishable from another ("the future"). Clearly, this

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[43] Stein uses the term "point" to refer to a space-time point.

[44] I am grateful to Robin Le Poidevin for pointing out this problem with Stein's argument.

assumption is a necessary component of any objectively distinguished present metaphysics in which past, present and future are each assumed to have a different existential status, or at least a different physical, if not existential, status. Time-orientation is implicit in Stein's claim that the state at a point a must be "subject to influence by the states at all points in the 'causal past' of a" (Stein 1991, p.149). Also implicit in this statement is the assumption of causality, a further addition to special relativity.[45]

Assuming a time-oriented, causal, spatio-temporal structure, Stein proposes a reality relation[46] R_p such that when the space-time point b stands in relation R_p to the space-time point a, that is, when R_pab, then b is definite as of a.[47] If b is definite as of a, then b is real as of a. The proposed relation R_p allows us to distinguish between a *definite* region of Einstein-Minkowski space-time (the past), and an *indefinite* region (the future), in compliance with the assumption of time orientation, as follows. Stein demonstrates that point a can only stand in the relation R_p to point b (that is, R_pab) where the vector from a to b is past-pointing. Stein shows that, if the vector is space-like, principle (iv) is violated. If the vector is future-pointing, a space-like vector can be constructed from it, and again principle (iv) is violated. He thus proposes:

> THEOREM. If R_p is a reflexive, transitive relation on a Minkowski space (of any number of dimensions – of course at least two), invariant under automorphisms that preserve the time-orientation, and if R_pab holds for some pair of points (a,b) such that ab is a past-pointing (time-like or null) nonzero vector, then for any pair of points (x,y), R_pxy holds if and only if xy is a past-pointing vector. (Stein 1991, p.149, R in Stein's text replaced by R_p)

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[45] It is interesting to consider whether we can assume causality in a model universe without assuming time orientation, and whether we can assume time orientation without assuming causality. If one assumes that causes always *precede* effects, then assumption of causality seems to imply assumption of time orientation. There is considerable debate, however, as to whether causes could be simultaneous with, or subsequent to, their effects (confer, for example, Tooley 1997). Thus assuming causality will only entail that we assume time orientation on a particular reading of causality (although we will still need the concept of time orientation to understand what is meant by a prior, simultaneous or subsequent cause). Assumption of time orientation, on the other hand, does not appear to imply assumption of causality, since it is possible to conceive of distinguishing between the past and future, without assuming that the future was caused by the past. Whether in practice, however, it would be possible to distinguish past from future without reference to cause remains to be seen. We will consider this issue again in chapter 7.

[46] I have labeled Stein's reality relation R with a subscript p (for presentist), to distinguish it from Putnam's reality relation.

[47] Note, in relation to footnote 37, that it is appropriate for Stein to define R_p:$R_pab \leftrightarrow$ state at b is definite as of a, where R_p is the criterion of reality. It would make less sense if R_p were the criterion of existence, since this would imply that all definite states exist. Stein interprets definite states as past states. The claim that the past exists is contrary to presentist metaphysics. The claim that the past is real need not be.

As we have noted, Stein is careful to define R_p in such a way that it does not violate any principles of special relativity.[48] Nonetheless, R_p is consistent with an objectively distinguished present metaphysics in which a determinate past can be distinguished from an indeterminate future. Whether R_p is specifically consistent with presentism, however, is open to question, since it seems to throw into doubt the status of things which are simultaneous with point a.

It can be objected that the definition of R_p depends crucially upon principle (iv), the assumption that the future is "not yet settled", and upon the introduction of time-orientation and causality into the Einstein-Minkowski structure. However, the advantage of Stein's reality relation in terms of definiteness over RPM's reality relation in terms of simultaneity, from Stein's point of view, is that it appears to render presentism, or at least some form of objectively distinguished present theory, compatible with special relativity. Nonetheless, it remains the case that RPM's assumption of a reality relation in terms of simultaneity, a relation which, apparently, any presentist would accept, leads to the conclusion that presentism is incompatible with special relativity. This must invite a reappraisal of presentism, regardless of whether it is possible to formulate other reality relations which do not lead to this conclusion. It is not therefore clear that Stein has achieved much by way of a counter-argument against RPM.

Furthermore, it is possible to object that R_p is not in fact satisfactory as a reality relation, independent of what temporal metaphysics one entertains. If *I*-now employ R_p as my reality relation, *I*-now must apparently conclude that things with which *I*-now am simultaneous are not real. Only things which are definite, things in my "causal past", are real. This conclusion does not appear to be compatible with a presentist metaphysics in which things become real in the (universal) present, the very metaphysics which Stein's proposed reality relation was designed to support. Clifton and Hogarth (1995), in a detailed analysis and development of Stein's argument, acknowledge this difficulty.

[48] Indeed, the light cone of a point, one half of which is interpreted by Stein as the causal past of that point, is well-defined in special relativity. On the other hand, as we have seen, the complaint can be raised that the simultaneity hyperplane of a point, although it does not conflict with the geometry of special relativity, is nonetheless defined by convention.

> "[T]he relations of past chronological and causal connectibility do not, as becoming relations should, provide for a spatio-temporally extended 'now'."[49] (Clifton and Hogarth 1995, p.381)

However, they query the assumption that a presentist metaphysics requires an extended "now" (a universal hyperplane of simultaneity with *I*-now) and suggest that the boundary between what does and what does not lie in the causal past of "here and now" is more convincing as a boundary between a definite past and an indefinite future than the simultaneity hyperplane defined with respect to "here and now".

> "[F]or advocates of indeterministic becoming candidates like I^- and J^- *already* look more promising than taking simultaneity places to partition what is unfixed or unsettled in the future from what is fixed in the past."[50] (Clifton and Hogarth 1995, p.383)

Clifton and Hogarth's response still does not explain what reality, if any, *I*-now am entitled to attribute to things, including observers, with which *I*-now am simultaneous. The problem remains that using R_p to define what is real seems to imply a solipsistic determination of reality, by limiting reality to *my* "here and now" and everything in the causal past of my "here and now". Perhaps we should interpret R_p as defining what I can be sure is real, and add the assumption that other observers simultaneous with me are also entitled to ascribe reality to themselves and their causal pasts. If we do not add this assumption, then it seems that only *my* causal past is real, without explanation of why my reference frame is to be so privileged. But if we do add this assumption then a problem arises similar to the one described by RPM. Observers in my simultaneity hyperplane may define different simultaneity hyperplanes. Why then should my simultaneity hyperplane, rather than some other observer's simultaneity hyperplane, be selected as determining which observers are entitled to ascribe reality to themselves?

Stein's R_p relation, even in the technically bolstered form proffered by Clifton and Hogarth, is not sufficient to ensure the compatibility of a presentist metaphysics

[49] Chronological and causal connectibility are Clifton and Hogarth's development of Stein's original R_p relation. Becoming relations are what I have referred to as reality relations. Within a presentist metaphysics, things become real, rather than being real at each space-time point, as is the case in a static block universe.

[50] I^- and J^- denote, in the nomenclature of special relativity, the boundary between what does and what does not lie in the causal past of a space-time point.

with special relativity, and indeed, if a presentist were to adopt R_p as the reality relation, it seems that such a presentist would be required to abandon a central tenet of presentist metaphysics, namely the assumption that things become real in the (universal) present. At this point, the problems with R_p might be interpreted as implying that special relativity is compatible with a static block universe metaphysics, but incompatible with a presentist temporal metaphysics. However, before drawing this conclusion, let us examine Stein's own response.

Stein appears to be willing to relinquish the assumption of "present [spatially distant] actualities" (Stein 1991, p.152), the assumption that things in the universal simultaneity hyperplane of an observer are real. Indeed, he criticizes RPM for making this assumption, an assumption which is essential as the starting point of their argument for a block universe, and points out with some justification that it is fundamental to special relativity "that it rejects any such notion" (ibid.). Just as Stein requires assumptions about time-orientation and causality in order to formulate his R_p relation, assumptions which are not implied by special relativity, so RPM can be seen, in their choice of simultaneity as their reality relation, to require an assumption which has its origins in presentist temporal metaphysics. There is nothing in special relativity to suggest that things in the universal simultaneity hyperplane of an observer should be considered real. Therefore, we must acknowledge that RPM's argument, like Stein's, imports an assumption which is not implied by the theory of special relativity. However, given that RPM are importing a presentist as opposed to a static block universe assumption, and given that their aim is to show that presentism is not compatible with special relativity, Stein's criticism of their use of an assumption which is not implied by special relativity carries little weight.

In this context, however, it is perhaps worth recalling that Einstein formulated special relativity under the influence of Mach, an operationalist who would have regarded any attempt to extract an underlying metaphysics from the theory, or make the theory compatible with a metaphysics, to be absurd. The operationalist doubt which may remain in regard to RPM's argument, therefore, is whether it is legitimate to import any metaphysical assumptions at all into a physical theory with the purpose of assessing whether the physical theory is compatible with a metaphysical theory. If we are to take an operationalist approach to theory formulation, it is difficult to see how special relativity on its own can be used to justify any temporal metaphysics, unless a reality relation can be formulated in special relativity which does not require any metaphysical assumptions at the outset.

Although operationalism has its merits, it is somewhat limiting as an approach to physical theory. There is no reason in principle why the consequences of adopting a particular metaphysical assumption should not be explored in the context of a theory of physics, and RPM can be seen to be doing just that. Given their results, however, it is fitting to consider, at this juncture, whether special relativity is even appropriate as the arbiter of our temporal metaphysics.

(e) The Limited Applicability Of Special Relativity

When Kurt Gödel, some twenty years before Putnam, set out to derive almost exactly the same conclusion as Putnam, he was clearly aware of the possibility of doing so on the basis of special relativity, the theory on which Putnam based his argument.

> "The very starting point of special relativity theory consists in the discovery of a new and very astonishing property of time, namely the relativity of simultaneity, which to a large extent implies that of succession."[51] (Gödel 1949a, p.557)[52]

Gödel goes on to express, very concisely, essentially the same argument that Putnam was later to develop. However, Gödel did not pursue the attempt to deduce the equivalent existential status of past, present and future from special relativity. Instead he used some solutions to the equations of *general* relativity, solutions which he had recently derived, as the basis of his argument. Gödel's argument is examined in detail in the next chapter. The important point to observe here is his reason for not pursuing the argument on the basis of special relativity, namely his recognition of the limited applicability of the theory.

> "[I]t can be objected that the complete equivalence of all observers moving with different (but uniform) velocities, which is the essential point in it[53], subsists only in the abstract space-time scheme of special relativity theory and in certain empty worlds of general relativity theory." (Gödel 1949a, p.559)

Quite aside from any technical difficulties with Putnam's argument, the fact that the theory of special relativity only applies to universes which do not contain matter, and in

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[51] That is, special relativity implies the relativity of succession.

[52] The page number refers to Gödel 1949a as printed in Schilpp 1949.

[53] That is, the argument on the basis of special relativity.

which bodies do not undergo acceleration, limits the significance of any conclusion drawn on the basis of the theory.

5 Special Relativity In The Context Of Other Theories Of Physics

Although Clifton and Hogarth's abbreviation RPM (confer footnote 40) links Maxwell with Rietdijk and Putnam, it should be observed that Maxwell, in the paper "Are Probabilism And Special Relativity Incompatible?" (Maxwell 1985), advocates a presentist metaphysics in opposition to the static block universe metaphysics espoused by Rietdijk and Putnam.

Where Maxwell concurs with Rietdijk and Putnam is in concluding that special relativity is incompatible with presentist metaphysics, and for essentially the same reason that they do, namely the argument that the geometric structure of space-time described by special relativity implies that states of affairs in the future (and indeed the past), relative to some arbitrary observer's now, exist in the same way as states of affairs in the present of that observer. Maxwell expresses this point in terms of the apparent impossibility of introducing within special relativity a distinction between past and future regions of space-time without reference to a particular inertial frame. The underlying problem, as we have seen, is that the simultaneity hyperplane of a particular observer is specific to that observer's inertial frame. As Putnam demonstrates, this leads to the conclusion that one observer will calculate to be in his future, or past, things which another observer, in motion relative to the first observer, calculates to be in his present. Consequently the distinction between what is past, present and future appears to be relative to an inertial frame, leading Maxwell to express the problem with special relativity as follows.

> "According to special relativity, given any two physical events, $E1$ and $E2$, having space-like separation from each other (so that they lie outside each other's past and future light cones), then there is no absolute, frame-independent way in which $E1$ is unambiguously either earlier than, simultaneous with, or later than $E2$." (Maxwell 1985, p.23)

Maxwell contrasts the type of universe which he takes to be implied by special relativity with the type of universe which he takes to be implied by what he terms probabilism. Probabilism is essentially the version of an objectively distinguished present theory with which Stein works, in which the future is "open" or indefinite and the past is "closed" or definite, so that at the present moment of time, it is possible for different futures to ensue.[54]

> "Probabilism, as understood here, is the thesis that the universe is such that, at any instant, there is only one past but many alternative possible futures." (Maxwell 1985, p.23)

Maxwell refines the concept of probabilism by drawing a distinction between ontological probabilism and predictive probabilism. According to ontological probabilism, the possibility of different futures ensuing from the present moment of time is a real, as opposed to imagined, possibility: "*the future is now in reality open with many ontologically real alternative possibilities*" (ibid., p.25, Maxwell's emphasis). Future states of affairs have yet to come into existence on this view, and consequently the future is indefinite. This version of probabilism, therefore, incorporates an objectively distinguished present metaphysics in which present states of affairs exist, but future states of affairs do not.[55] Predictive probabilism, on the other hand, assumes that the possibility of different futures ensuing from the present moment of time is only an imagined possibility. We imagine that different futures are possible because we never have sufficient information in the present to predict the future, although there is in reality only one possible future.

> "[A]lternative possible futures represent no more than alternative possibilities relative to what can in principle be predicted on the basis of a complete specification of the present, and the basic laws: they are not alternatives *in reality*." (Ibid., p.25, Maxwell's emphasis)

[54] Probabilism resembles both growing block universe theories and growing determinacy theories to some extent.

[55] The precise status of past states of affairs is vague in Maxwell's account. For a presentist who wishes to claim that only present states of affairs exist, it would be misleading to claim that past states of affairs exist. Yet some distinction between past and future states of affairs must apparently be drawn. This is where a distinction between being real and existing may prove useful. The presentist could claim that past states of affairs are real (or definite) but do not exist, that present states of affairs are real and exist, and that future states of affairs are not real (not definite) nor do they exist. The same problem does not arise for a growing block universe theorist, who can assert that past and present states of affairs exist, but that future states of affairs do not. A growing determinacy theorist can assert that past, present and future states of affairs exist, but that they are distinguished in terms of their state of determinacy.

Predictive probabilism assumes a block universe metaphysics in which future states of affairs exist in the same way as past and present states of affairs. Consequently only one future is possible on this view.

Maxwell goes on to suggest that predictive probabilism is compatible with probabilistic laws: "*predictive probabilism* ... asserts that the future, like the past, is now in reality entirely fixed and determined even though the basic laws are probabilistic and not deterministic" (ibid., p.25, Maxwell's emphasis). What does it mean to say that a law is probabilistic in a universe where only one future exists? Presumably, since a law is intended to specify the outcome whenever a particular set of circumstances obtain, a probabilistic law implies that more than one outcome is possible when a particular set of circumstances obtain, and specifies the probability of each particular outcome. This implication appears relatively unproblematic in an objectively distinguished present universe, where the future is indeterminate. However, in most versions of both objectively distinguished present and static block universe metaphysics, on each occasion where a specified set of circumstances obtain, only one outcome is deemed to occur. In a static block universe, this outcome exists even relative to observers who calculate that it is in their future, and therefore no other outcome is ontologically possible. However, it is still meaningful to describe a law as probabilistic in this context, since the law is about all occasions throughout space-time where the appropriate set of circumstances occur. The law is therefore intended to describe the distribution of outcomes across all these occasions.

To say, for example, that the set of circumstances X has a 75% probability of giving rise to outcome Y, and a 25% probability of giving rise to outcome Z is to express the claim that, if there are 100 occurrences of X distributed through space-time, 75 are followed by Y and 25 are followed by Z. This statement does not preclude that, at any particular occurrence of X, the ensuing outcome is fixed, as it must be in a static block universe. An observer witnessing X can therefore speak of either Y or Z being possible outcomes, whilst ontologically only one outcome exists. It is clear, therefore, that it is meaningful to consider probabilistic laws in the context of static block universe metaphysics.[56]

With the distinction between ontological and predictive probabilism established, Maxwell speculates as to how one is to choose between them. Given the way in which he defines the two varieties of probabilism, the choice amounts to one between an objectively distinguished present and a static block universe metaphysics. However, although Maxwell concurs with Rietdijk and Putnam in concluding that special relativity is not compatible with ontological probabilism (that is to say, it is not compatible with presentism), he draws the opposite conclusion to them. He suggests that there must be a problem with special relativity, rather than with his version of an objectively distinguished present theory. A major factor in reaching this conclusion is Maxwell's belief that at least some interpretations of quantum mechanics, including his preferred one, imply ontological probabilism.

In referring to quantum mechanics, Maxwell clearly distinguishes his methodology from that of Rietdijk and Putnam. Neither of them consider any theory of physics other than special relativity in formulating their argument. Their adherence to special relativity can be interpreted in at least three different ways. (i) It can be interpreted as an expression of the belief that all other theories of physics imply the same temporal metaphysics as special relativity (that is, a static block universe metaphysics[57]). (ii) It can be interpreted as an expression of the belief that we should accept the temporal metaphysics implied by special relativity in preference to different temporal metaphysics implied by other theories of physics. (iii) Or it can be interpreted as an expression of the belief that *only* special relativity implies a temporal metaphysics. That is, we cannot deduce a temporal metaphysics from other theories of physics.

Clearly, all three of these interpretations are open to question. Maxwell evidently assumes that, amongst the theories of physics, at least one interpretation of quantum mechanics implies a temporal metaphysics, that the metaphysics which it implies is not the same as the metaphysics implied by special relativity, and that the metaphysics implied by special relativity should not automatically take precedence over the metaphysics implied by this interpretation of quantum mechanics. Indeed, if anything, Maxwell appears to prefer the metaphysics implied by his interpretation of quantum mechanics over the metaphysics implied by special relativity. This is what leads him to propose that, if the metaphysics implied by special relativity is irreconcilable with his version of an objectively distinguished present theory, then the problem lies with special relativity. Whether Maxwell is any more justified in preferring the metaphysics implied by his interpretation of quantum mechanics than Rietdijk and Putnam are in preferring the metaphysics implied by special relativity

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[56] This will be a useful point to bear in mind when we consider quantum mechanics in detail in chapter 7.

[57] This is setting aside, for now, the issue which we have already considered, namely, whether special relativity implies a temporal metaphysics at all.

remains to be seen. We will examine this in detail when we consider quantum mechanics in chapters 6 and 7.

The main point to observe at this juncture is that we cannot, as Rietdijk and Putnam appear to do, simply assume that a temporal metaphysics, that of the static block universe, is implied by special relativity, and that this is the temporal metaphysics which we must accept as the correct description of our universe. It is illegitimate to propose such a conclusion prior to the analysis of other theories of physics to see what temporal metaphysics, if any, they imply, and a consideration of how we are to choose between temporal metaphysics, if different theories of physics imply different metaphysics. If we are required to choose between temporal metaphysics, should it be on the basis that the metaphysics implied by the "best" theory of physics is to take precedence? In that case, how are we to assess which is the "best" theory of physics?

As indicated above, Maxwell considers that his favoured interpretation of quantum mechanics (which he terms the propensity version[58]) implies an objectively distinguished present metaphysics. On this basis, he is obliged to reject special relativity which, in accordance with Rietdijk and Putnam, he takes to imply a static block universe metaphysics. It is interesting to note, therefore, that Maxwell suggests that it is general, rather than special, relativity which must be modified "to render it *compatible* with probabilism" (ibid., p.40, Maxwell's emphasis), presumably on the grounds that, as the name implies, general relativity is a more general theory than special relativity. He sketches what would be required of a version of general relativity "in which there exists in space-time a unique set of temporally successive, spacelike hypersurfaces, to constitute successive cosmic or universal 'nows'. These hypersurfaces then need to be related to the presence of *matter...*" (ibid., p.40, Maxwell's emphasis).

Clearly, if general relativity could be made compatible with quantum mechanics, and if the resulting theory implied an objectively distinguished present metaphysics, this would lend greater support to an objectively distinguished present metaphysics than special relativity does to a static block universe metaphysics. However, general relativity and quantum mechanics have not been unified as yet, and as we will see in the next chapter, general relativity on its own is as potentially problematic as special relativity for an advocate of an objectively distinguished present metaphysics. Indeed, there is no basis for assuming that the union of general relativity

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[58] I will not consider Maxwell's propensity version of quantum mechanics in detail. However, Maxwell's theory resembles, in a number of salient respects, the spontaneous localization theory which is described in chapter 7, section 2, so the description there provides the basic import of Maxwell's thinking.

with quantum mechanics would necessarily imply an objectively distinguished present metaphysics rather than a static block universe metaphysics. To that extent, Maxwell's assumption that general relativity must be made compatible with probabilism, rather than, say, making quantum mechanics compatible with a static block universe, could be seen as presupposing an objectively distinguished present metaphysics without justification. However, the importance of Maxwell's paper is not its defence of an objectively distinguished present metaphysics, but its illustration that theories of physics other than special relativity may imply temporal metaphysics which conflict with the static block universe temporal metaphysics that some philosophers have taken to be implied by special relativity.

6 Conclusion

In this chapter, I have considered the argument that special relativity implies a static block universe metaphysics, in particular the argument in the form given by Putnam (1967). I have illustrated, by means of truth values, that a static block universe is a determinate universe, but not necessarily a deterministic universe. I have also shown that a number of problems exist for the argument from special relativity, stemming in particular from the assumption that if *I*-now am simultaneous with a thing, that thing is real. The definition of simultaneity within special relativity was seen to be conventional, the possibility that simultaneity might be defined by non-relativistic means was considered, and the assumption that if I am simultaneous with some thing, I am warranted in attributing reality to that thing was challenged. These considerations led us to the observation that the equation between simultaneity and reality is a metaphysical assumption, the employment of which is essential to the argument that a static block universe metaphysics is implied by special relativity. It was indicated that special relativity is of limited application to the universe we actually inhabit, and it was also pointed out that other theories of physics may be interpreted as implying an objectively distinguished present temporal metaphysics, which conflicts with the static block universe metaphysics apparently implied by special relativity.

Markosian (2004) succinctly expresses the problems which abound in assessing the implications of special relativity for temporal metaphysics. He identifies two versions of special relativity, STR^+ and STR^-. He describes STR^+ as a "philosophically robust version of STR" which implies that "there is no such relation as absolute simultaneity" and STR^- as a "philosophically austere version of STR" which does not imply that "there is no such relation as absolute simultaneity".

Even if we do interpret special relativity as necessitating a static block universe metaphysics, we must acknowledge that special relativity is only one of at least four distinct theories of modern physics (special relativity, general relativity, thermodynamics, and quantum mechanics), each of which may be interpreted as implying a temporal metaphysics. So *if* we are justified in basing our temporal metaphysics on physics, we are only justified in basing our temporal metaphysics on a consideration of *all* of these theories, unless we can demonstrate that one of them takes precedence over the others.

3

General Relativity And Existential Change

1 Introduction

We saw in the previous chapter that some philosophers have argued that special relativity implies a static block universe metaphysics of time. It is also possible to argue for such a metaphysics on the basis of general relativity. In his paper "A Remark About The Relationship Between Relativity Theory And Idealistic Philosophy" (Gödel 1949a), the logician Kurt Gödel demonstrates that Einstein's field equations, the equations which form the basis of general relativity, can be interpreted as implying a static block universe metaphysics. The argument is different from the argument on the basis of special relativity, though as we shall see some of the underlying assumptions are the same. In particular, the form of Gödel's argument implies that there is only one metaphysics of time compatible with general relativity, and that the metaphysics implied by general relativity is to take precedence over any other metaphysics, on the grounds that general relativity itself is not dependent upon metaphysical assumptions. These two assumptions exactly parallel assumptions made by Putnam, and as before, they can be challenged.

I will begin by considering Gödel's concept of change in detail, since this will serve to clarify a number of aspects of his argument. I will then consider why, although Gödel considers an argument for a static block universe metaphysics of time based upon special relativity, an argument similar to the one which Putnam employs, he rejects it as a convincing argument. As we will see, Gödel turns instead to general relativity in formulating his argument for a static block universe metaphysics. I will therefore go on to analyze the structure of his argument based upon general relativity.

In the course of this analysis, I will examine why Gödel considers that there are certain universes which can be modelled on the basis of Einstein's field equations which can only be appropriately described in terms of a static block universe temporal metaphysics.

I conclude the chapter with an assessment of whether Gödel's argument for a static block universe metaphysics is more convincing than Putnam's, given the problems which we have already observed to exist for the argument on the basis of special relativity.

2 Gödel's Argument For The Equivalent Existential Status Of Things

In essence, Gödel takes the mathematical models which he constructs within general relativity to imply, or at least strongly suggest, that "no objective lapse of time can exist" (Gödel 1949a, p.562). We need to consider what he means by an "objective lapse of time", why he considers that general relativity implies that such a lapse cannot exist, and whether this claim is equivalent to the claim that things in the past, present and future of an observer have the same existential status. Prior to this analysis, it should be noted that 1949a and its preceding drafts represent Gödel's one serious foray away from mathematics into the philosophy of time[1], and as such some might question the paper's virtue in philosophical terms. Gödel certainly lacked any extensive philosophical training and this in part gives rise to the "enigmatic" quality of his terminology. Nonetheless, I would suggest that the terms in which he expresses the argument of 1949a evince sustained careful thought about the concept of time, and I therefore consider his argument worthy of detailed philosophical analysis.

(a) Gödel's Concept Of Change

Gödel gives a relatively clear, but very concise, account in 1949a of what he takes "change" to consist in.

> "Change becomes possible only through the lapse of time. The existence of an objective lapse of time, however, means (or, at least, is equivalent to the fact) that reality consists of an infinity of layers of 'now' which come into existence successively." (Gödel 1949a, p.558)

[1] According to Wang (1995), however, Gödel remained intrigued by the problems associated with the concept of time well into the 1970's, without venturing to write again on the subject.

He adds a limited amount of clarification in a footnote to the passage quoted above where he refers to "the idea of an objective lapse of time (whose essence is that only the present really exists)" and in the subsequent footnote where he refers to "the lapse of time in the ordinary sense, which means a change in the existing".

An immediate problem with Gödel's statement is in what he takes a "layer of 'now'" to consist. He appears to intend by this a *smooth global spacelike hypersurface*, to employ the terminology of general relativity, which I will refer to as a *time slice* for convenience. In the context of special relativity the typical time slice is a simultaneity hyperplane, the term used in the previous chapter. However, the term "simultaneity hyperplane" has no invariant meaning in general relativity so in the context of general relativity I shall speak of time slices. As we will see, it will also be convenient to equate time slices with moments of time.[2]

Gödel is going to demonstrate that a layer of "now" cannot be defined within at least some universes which obey the laws of general relativity. However, it seems apparent that a layer of "now", where it can be defined, consists of the moment of time which all observers, regardless of their spatial location, agree upon as the present.

Gödel also states that "Change becomes possible only through the lapse of time", suggesting that he does not equate change with the lapse of time. He appears to be distinguishing change from the lapse of time given his statement that change *becomes possible* only if time lapses, and I will examine below how we might understand this distinction. Gödel goes on to claim that, for time to be said to lapse, it must be the case that "reality consists of an infinity of layers of 'now' which come into existence successively". Gödel is here depicting his version of an objectively distinguished present metaphysics, the metaphysics which he intends to disprove. He is essentially depicting a presentist metaphysics, as is evident when he equates "an objective lapse of time" with the claim that "only the present really exists".

The claim that "Change becomes possible only through the lapse of time" makes most sense if we take "change" to refer to change in physical objects. One possible reconstruction of the model which Gödel is envisaging is then as follows. For an object

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[2] The possibility of dividing time into moments, at least nominally, is one which I shall assume. We do, of course, divide time up into seconds, minutes, hours, days, weeks, months, years and so on. These latter, it might be observed, all derive from the orbital velocity of the planet which humans inhabit, the Earth, around the star nearest to that planet, the Sun. The question arises as to whether there is something intrinsic about the duration of a moment which distinguishes it from these other possible divisions of time, all of which appear to be dependent upon the location of humans in the universe. Another way of putting this would be to ask whether time slices have an intrinsic temporal "thickness". I will not attempt to answer this question here.

to change in the sense Gödel appears to require, it must be the case that the *whole* object has some property x at some moment of time t_1, and that the *whole* object lacks property x at some other moment of time $t_1 \pm \Delta t$, where Δt is some short duration of time.[3] In this case, the object can be said to have changed. A presentist metaphysics is compatible with physical object change conceived of in this way since this type of metaphysics requires that only the present moment exists.[4] This requirement implies that physical objects must exist in their entirety in the present moment. Therefore, if a physical object has a property at all, the whole object has that property, and if it subsequently lacks that property, it is the whole object which lacks that property. Therefore, it has undergone change in the sense Gödel appears to intend.

This interpretation of change makes sense of Gödel's statement that change "becomes possible" only through the lapse of time. The requirements that only the present moment exists and that this moment passes out of existence to be replaced by the next present moment must be met if objects, necessarily wholly existent in the only existing moment, the present, are to be considered genuinely to have changed. But it is the passing into and out of existence of the present moment, the "layer of 'now'", which Gödel is referring to when he speaks of the lapse of time, rather than the change in the physical objects existing at that moment. The distinction can be illustrated if we consider the case where a physical object changes none of its non-temporal properties between two consecutive moments of time, but nonetheless changes simply by virtue of the fact that it first existed at one moment but now exists at a different moment.[5]

In contrast, if we consider the concept of a physical object in a static block universe metaphysics, we can see why change, in Gödel's terms, does not occur in a universe which conforms to this metaphysics. In a static block universe, a physical object is a four-dimensional entity extended through time as well as through space. Therefore, if the object has some property x at some moment t_1, and lacks that property x at some other moment $t_1 \pm \Delta t$, it is simply the case that the temporal part of the object located at the moment t_1 has the property x and the temporal part of the object located at the moment $t_1 \pm \Delta t$ lacks the property x. Taken as a whole the object has two properties, $x(t_1)$ and $\neg x(t_1 \pm \Delta t)$. If one part of an object has one property and another part of the

[3] The moment $t_1 \pm \Delta t$ is therefore some moment earlier or later than the moment t_1.

[4] I shall leave aside for now the issue of whether or not it is coherent to conceive of non-present moments as real although non-existent.

[5] It may be that the non-temporal properties of an object, for example, the positions of the atoms composing the object, always change from moment to moment anyway. The theoretical situation in which no such changes occur is considered to illustrate the distinction to which, I believe, Gödel is alluding.

same object has another property, this does not amount to change in Gödel's terms. It must be the case that the *whole* object has a property at some moment, and the *whole* object lacks that property at some other moment, for the object to be said to have changed. We can see therefore that physical objects as conceived of in a static block universe metaphysics *never* undergo change in this sense, since they are complete four-dimensional entities as opposed to three-dimensional entities in this conception.[6]

The foregoing analysis suggests that change in physical objects in Gödel's sense is only compatible with a presentist metaphysics, where to state that a physical object has changed is taken to mean that the whole physical object exists in one state at one time and in a different state at some other time. This, I would suggest, is the most coherent interpretation of what Gödel intends by the term "change", given his explanation of what he means by the "lapse of time". We might of course observe that it is possible to formulate alternative concepts of change[7], but it certainly appears to be the case that the concept of change we have just been examining is the one which makes most sense in the context of a presentist metaphysics. It will be convenient, therefore, to distinguish change in the sense in which Gödel is using the term from other possible concepts of change. I shall henceforth refer to Gödel's concept of change as *non-incremental existential change*, on the grounds that an object undergoes non-incremental *existential change* if it wholly exists at each moment. For brevity, I will refer to non-incremental existential change simply as existential change, unless it is being discussed in comparison to *incremental existential change*, which I take to be the type of change undergone by objects in a growing block universe.

I am only going to consider non-incremental existential change in this chapter, since Gödel's argument is specifically directed against presentism, the type of objectively distinguished present theory in which non-incremental existential change is envisaged to occur. It should be borne in mind, however, that Gödel's argument, if sound, would count against growing block universe and growing determinacy theories as well.

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[6] In a growing block universe theory, physical objects are growing four-dimensional entities.

[7] In a growing block universe theory, an object is extended through time and composed of temporal parts, as in a static block universe. However, the number of temporal parts of the object are continually increasing, as new moments of time come into existence, for as long as the object continues to exist. In a growing block universe, therefore, change in physical objects arises from accretion of temporal parts.

A growing determinacy theory would give a different account of change to either a presentist or a growing block universe theory. It is the state of determinacy of physical objects which change in such a theory, rather than their state of existence.

(b) Necessary And Sufficient Conditions For Existential Change

It seems apparent that for existential change as I have just defined it to occur, the restriction of existence to the present moment is necessary. It is therefore useful to consider whether this restriction is also sufficient for existential change. Consider a physical object wholly existing at the moment t_1. Assuming that the physical object endures, does the whole existence of the object at some other moment $t_1 \pm \Delta t$ amount to existential change?

(i) A Presentist Account Of Existential Change

Consider a universe containing just one physical object. If the present moment of time is conceived of in presentist terms, then we can envisage that the present moment in our one object universe could go out of existence, and a new present moment could come into existence, even if the object did not change any of its non-temporal properties from the one moment to the next. We can then ask, does the object wholly existing at one present moment and its wholly existing at another present moment amount to the object's having undergone existential change?

Observe first of all that one present moment must be intrinsically different from another present moment, otherwise it would be the same moment.[8] Since, therefore, there must be an intrinsic difference between moments, we can index the existence of an object both to the moment in which it is currently wholly existing and also to the moment in which it first existed. That is, it is legitimate to attribute the two properties of *location in time* (Loc)[9] and of *age* (Age) to a physical object in a presentist model.

Consider the moment t_1 at which a physical object P comes into existence. We can attribute at least two temporal properties to P.

(Loc) P wholly exists at t_1.

(Age) P has wholly existed at 0 moments prior to t_1.

At the next moment, t_2, P has two temporal properties again.

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[8] Of course, a physical object, conceived of as wholly existing at a particular moment, could not be in a different state now to a state it was in previously unless it now existed in a different moment to the moment in which it had existed. Thus a change in the non-temporal properties of a physical object certainly *indicates* a change in moments. However, the moments would be different even if the physical object had not changed any of its non-temporal properties.

[9] I shall use bracketed three letter abbreviations, with an additional one letter subscript where appropriate, to refer to the various temporal properties.

(Loc) P wholly exists at t_2.

(Age) P has wholly existed at 1 moment prior to t_2.

Clearly, P at t_2 has at least two different properties to the properties it had at t_1, and since it wholly exists at each moment, it has undergone existential change. In general, for as long as a physical object exists, it is always possible to ascribe a location in time and an age to that object. The property of location in time has the general form:

(Loc) P wholly exists at t_n.

The variable t_n denotes the moment then present. The property of age has the general form:

(Age) P has wholly existed at $(n\text{-}1)$ moments prior to t_n.

I am assuming that n is a non-negative integer, which implies that moments are discrete. This is a convenient simplification at this stage of the analysis, but even if a more complex concept of a moment turned out to be required, the main point to observe here is that a physical object will always have at least two properties which change between moments in the presentist view.

Therefore, we can conclude that restricting the existence of a physical object to the present moment is sufficient for existential change of that object to occur. The whole existence of the object at the moment t_1 and again at some other moment $t_1 \pm \Delta t$ implies that at least two of the properties which the object has at $t_1 \pm \Delta t$, its location in time and its age, have changed from what they were at t_1. This is sufficient for the object to be deemed to have undergone existential change.

(ii) Why Existential Change Does Not Occur In A Static Block Universe

It is interesting to observe the effect of not restricting the existence of a physical object to the present moment, the situation envisaged in a static block universe. If we consider a static block universe model for purposes of comparison with a presentist model, we can observe that the properties of location in time and of the age of a physical object have to be formulated differently. Rather than locating the whole object at a particular moment, as in a presentist account, we are required to locate a temporal part of the object at a moment, recalling that in the static block universe model an object is a four-dimensional rather than a three-dimensional entity, and is therefore extended through time as well as in space. The property of location in time of a temporal part (Loc_p) is therefore stated in the form:

(Loc_p) Temporal part p_n of the physical object P exists at t_n.

The variable n is a non-negative integer as previously. If we wish to state the temporal location of the object P as a whole, (Loc_w), we need to state it in the form:

(Loc_w) P exists at the range of moments from t_1 to t_z.

The variable z denotes the number of moments which the four-dimensional object occupies.[10] The duration (Dur) of P is therefore stated in the form:

(Dur) P exists for z moments.

The variable z is as just defined. We can talk about the age of the object at a particular moment within the range t_1 to t_z, stating its age in the form:

(Age) There are (n-1) temporal parts of P existing prior to moment t_n.

This assumes that a direction through time is defined such that it is clear which moments are taken to be prior to the moment t_n.[11]

It should be evident that neither the location in time nor the age of a physical object in a static block universe, as these properties have just been defined, are subject to change. For example, if a four-dimensional object occupies the range of moments from t_1 to $t_{10,000}$, this is the case from the point of view of *any* moment in the universe. Consider the property (Loc_w) of the object.

(Loc_w) P exists at the range of moments from t_1 to $t_{10,000}$.

Clearly, (Loc_w) does not change. Similarly, we can see that (Age), relative to any

[10] The designation t_1 is chosen to denote the first moment at which the object exists. The subscript "1" should not, however, be taken to imply that this is necessarily the first moment in the universe as a whole.

[11] I examine the direction of time in detail in chapter 5.

particular moment, is unchanging. If there are 4,999 temporal parts of the object existing at moments prior to moment to $t_{5,000}$, this is the case from the point of view of any moment.

(Age) There are 4,999 temporal parts of P existing prior to moment $t_{5,000}$.

The unchanging nature of location in time and age in a static block universe can be seen to arise from the fact that a physical object in such a universe is not restricted in its existence to a single moment, but is rather envisaged as existing across a range of moments. It does not appear that location in time or age could be defined in such a way as to permit change whilst remaining compatible with this aspect of a block universe metaphysics. As we might expect, therefore, the attribution of a location in time and an age to a physical object in a static block universe will not be sufficient conditions for the object to be considered to undergo existential change. This conclusion emphasizes the close connection between the restriction of the existence of a physical object to the present moment and the ability of that object to undergo existential change.

(c) Gödel's Examination Of The Argument From Special Relativity

It is Gödel's intention in 1949a to "deny the objectivity of change" (p.558), thereby, as he interprets the situation, aligning himself with "Parmenides, Kant, and the modern idealists"[12] (p.558). "Objective" change for Gödel, it seems apparent, is what I have termed existential change, that is, an actual change in the state in which a whole physical object exists from moment to moment, rather than a difference between the temporal parts of a temporally extended object in a static block universe.[13] The alternative to assuming that existential change occurs, according to Gödel, is to "consider change as an illusion or an appearance due to our special mode of perception" (Gödel 1949a, p.558). If we do inhabit a static block universe, then we are mistaken if we interpret our perception of the difference between the temporal parts of an object as

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[12] It is not clear that Gödel is in fact as closely aligned with these other philosophers as he takes himself to be. Gödel's argument, as we will see, implies that our experience of existential change is not correlated to any underlying physical conditions of the universe, an implication which might be interpreted as supporting the idealist claim that we need to distinguish between appearance and reality. However, Gödel also appears to be assuming that we can come to know the true nature of reality by examining mathematical models derived from theories of physics. An idealist such as Kant would deny that we can come to know the true nature of reality, "das Ding an sich selbst" ("the thing in itself") (Kant 1787, p.45), by any means.

[13] It could of course be argued that "objective" change could take the form of incremental existential change, as in a growing block universe, or change in determinacy, as in a growing determinacy. Gödel does not consider these alternatives.

evidence of existential change.

How could the perception of different temporal parts of a four-dimensional object give rise to the illusion of existential change? One possible answer is that it is "our special mode of perception", as Gödel calls it, which gives rise to the appearance of existential change, but the appearance masks the reality. Since the issue does not appear to be immediately resolvable, I will leave it to one side and concentrate on how Gödel sets about attempting to demonstrate that we do in fact inhabit a block universe.

As noted in the preceding chapter[14], Gödel was aware of the argument for a static block universe metaphysics on the basis of special relativity. We examined in detail in that chapter why it is that a *privileged* time slice[15], one of Gödel's "layers of 'now'", cannot be defined on some interpretations of special relativity, and we saw how the failure to define such a time slice leads to the implication that things which one observer defines to be in the past or future have the same existential status as things which that observer defines to be in the present. In 1949a, Gödel rehearses this argument, expressing it in the following manner.

> "[I]f simultaneity is something relative in the sense just explained, reality cannot be split up into such layers [of 'now'] in an objectively determined way. Each observer has his own set of 'nows', and none of these various systems of layers can claim the prerogative of representing the objective lapse of time." (Gödel 1949a, p.558)

Gödel is here setting out the structure of the argument on the basis of special relativity. If a privileged time slice cannot be defined in a universe, then the presentist claim that only the present moment, a single layer of 'now', exists appears incoherent, given that it is not clear in such a universe which time slice corresponds to the present moment. Special relativity implies that simultaneity is relative to an observer, and therefore a privileged time slice, agreed upon as such by all observers, cannot be defined in a universe which is adequately described by special relativity.

However, Gödel does not consider that the argument from special relativity is sufficient to show that a presentist metaphysics is inapplicable to our universe, since he

[14] See chapter 2, section 4 (e).

[15] A time slice is privileged if it is distinguished in some way from other possible time slices which might be defined. For example, a time slice might be considered privileged if it is defined by an observer whose motion follows the mean motion of matter in the universe.

does not consider that the type of universe which we inhabit *is* adequately described by special relativity. He points out that special relativity only applies to a particular range of possible[16] universes, that range of universes which are empty of matter.

> "[T]he complete equivalence of all observers moving with different (but uniform) velocities ... subsists only in the abstract space-time scheme of special relativity theory and in certain empty worlds of general relativity theory." (Gödel 1949a, p.559)

That is, special relativity only adequately describes a range of possible universes into which the type of universe we inhabit, one containing matter, does not obviously fall. Having acknowledged the argument from special relativity, therefore, Gödel has effectively dismissed it. Nonetheless, the structure of the argument which he is going to pursue is similar to that employed in the argument on the basis of special relativity, namely that a presentist metaphysics cannot be coherently formulated for a universe in which a privileged time slice cannot be defined. However, as we will see, Gödel's strategy will involve modelling a universe in which no time slices, understood here specifically as global time slices, can be defined at all. In this situation, the possibility of defining a time slice as the physical instantiation of the present moment is ruled out.[17]

(d) Can Presentism Be Reconciled With General Relativity?

Gödel has just rejected any argument against presentism based on special relativity. Instead he is going to formulate his argument against presentism on the basis of general relativity. One of the features of universes described by general relativity, as we have already seen, is that they contain matter. However, this very feature presents Gödel with the most immediate obstacle to the formulation of his argument. Having just dismissed the argument based on special relativity, Gödel points out that as soon as matter is

[16] When I speak of a universe being "possible" in this sense, I mean one which conforms to the particular constraints of the physical theory. Special relativity is a set of mathematical equations. A whole range of different universes are definable in accord with these equations, each one therefore a "possible" universe. Note that Gödel uses the term "world" where I use the term "universe".

[17] Neither a growing block universe nor a growing determinacy metaphysics can be formulated for a universe in which global time slices cannot be defined. Thus, although Gödel directs his argument against presentism, the same argument would also preclude the other two types of objectively distinguished present theory if it turned out to be sound. I will continue to focus upon presentism in the analysis of Gödel's argument, since this is the only type of objectively distinguished present theory which Gödel considers.

included in the model of a universe, the possibility of defining a privileged time slice reemerges, precisely the opposite of what he requires if he is to successfully argue against presentism.

> "The existence of matter, however, as well as the particular kind of curvature of space-time produced by it, largely destroys the equivalence of different observers and distinguishes some of them conspicuously from the rest, namely, those which follow in their motion the mean motion of matter." (Gödel 1949a, p.559)

All those observers whose motion follows the mean motion of matter in the universe as a whole, let us call them *mean motion observers*, will be able to define a time slice. It is clear from the analysis of special relativity which was conducted in the previous chapter that all mean motion observers, since they are all travelling with the same velocity, will define the same time slice. The time slice which all mean motion observers define as their present moment could then be considered to be the presentist's present moment, the only existing moment. It would no longer be necessary to award equal existential status to the different time slices defined by observers moving at velocities other than that followed by the bulk of matter in the universe. Let us call this latter type of observers *non-mean motion observers*. Any differences in the observations made by non-mean motion observers when compared with observations made by mean motion observers might reasonably be attributed to the physical effects upon non-mean motion observers resulting from their moving at velocities different to the velocity of the bulk of matter in the universe.

Therefore, the existence of matter in a universe modelled according to the constraints of general relativity actually serves to restore the privileged inertial frame which was absent from universes modelled according to special relativity. The privileged inertial frame is that inertial frame which is defined according to the mean motion of the matter in the universe. The time slice defined by any mean motion observers as their present moment, that is as the present moment within the privileged inertial frame, can then be interpreted as the only existing moment in the universe, thereby rendering such a universe compatible with a presentist metaphysics.

> "Now in all cosmological solutions of the gravitational equations (i.e., in all possible universes) known at present the local times of all *these* [mean motion] observers fit together into one world time, so that apparently it becomes possible

> to consider this time as the "true" one, which lapses objectively, whereas the discrepancies of the measuring results of other observers from this time may be conceived as due to the influence which a motion relative to the mean state of motion of matter has on the measuring processes and physical processes in general." (Gödel 1949a, p.559)

In this passage, Gödel refers to the gravitational equations. These are the equations which mathematically express the theory of general relativity. Until the late 1940s when Gödel was writing, all the solutions of these equations which had been formulated permitted a privileged inertial frame, and hence a privileged time slice, to be defined in relation to the mean motion of matter in a universe, a universe that is described by each particular solution to the equations. All such solutions, therefore, are compatible with a presentist metaphysics[18] which requires that a privileged time slice be definable. Clearly, if every possible solution to the gravitational equations permitted such a time slice to be defined, general relativity would be of little use to anyone wishing to argue that a static block universe, as opposed to a presentist, metaphysics is the correct description of the universe which we inhabit.

However, the reason that Gödel is drawing upon general relativity with the purpose of arguing against presentism is that shortly before writing 1949a, he had discovered some solutions to the gravitational equations which model universes which do not admit any foliation at all by time slices. The next step in the analysis of Gödel's argument, therefore, will consist in exploring Gödel's solutions to the gravitational equations, in order to understand why they describe a range of universes for which, apparently, no presentist metaphysics can be coherently formulated. A crucial question, however, one which Gödel only addresses in passing at the end of his paper, is whether the universe which *we* inhabit corresponds to any of the universes modelled by his solutions to the gravitational equations, and if not, what relevance his results have for our universe.

In this regard, it is worth observing that Gödel's reason for rejecting the argument from special relativity, the recognition that the range of universes which special relativity describes is not a range in which our universe is obviously located, could re-emerge as a reason for rejecting Gödel's own argument. As we have already noted, it appears to be the case that some solutions to the gravitational equations, those formulated before Gödel addressed the issue, model universes which are compatible with an objectively distinguished present metaphysics, whilst some, in particular those formulated by Gödel himself, do not. It might turn out therefore that the set of all possible solutions to the gravitational equations, taken as a whole, gives us no clear indication as to whether an objectively distinguished present or a static block universe metaphysics is the correct description of our universe. In that case we will need to find other criteria for selecting a particular subset of the solutions to the gravitational equations, before attempting to deduce from those solutions the appropriate temporal metaphysics for the universe we inhabit. If it turns out that the range of universes which are described by Gödel's solutions to the gravitational equations do not correspond to certain features of our universe, then this might be considered a good reason to conclude that these solutions are not an adequate description of our universe, just as Gödel concludes that special relativity is not an adequate description. I will leave these considerations to one side for now, however, in order to examine how Gödel argues on the basis of general relativity towards the conclusion that we inhabit a block universe.

(e) Gödel's Argument Against Presentism On The Basis Of General Relativity

The basis of the argument we are about to examine, as has already been suggested, is that if the spatio-temporal structure of a universe is such as to preclude the foliation of that universe by global time slices, then a presentist metaphysics is not an appropriate metaphysics for that universe, given that a presentist requires identification of a global time slice as the physical correlate of what we experience as the present moment. We need to understand, therefore, on what basis Gödel considers that general relativity implies a spatio-temporal structure which is incompatible with presentism.

Prompted by the request to write a paper for a volume[19] which would be dedicated to Einstein, Gödel had begun to examine the gravitational equations of general relativity. The results of this examination were set forth by Gödel in the paper "An Example Of A New Type Of Cosmological Solutions Of Einstein's Field Equations Of Gravitation" (Gödel 1949) which he published in the same year as he made his contribution to the Einstein volume. Whilst in the contribution to the Schilpp volume, usually referred to as Gödel 1949a, Gödel endeavours to adopt a broadly philosophical approach to his subject matter, his other published paper, Gödel 1949, consists of a description in mathematical terms of his new solutions to Einstein's gravitational equations. The solutions which Gödel describes in Gödel 1949 model universes which

[18] Or indeed either of the other two objectively distinguished present metaphysics.

rotate[20] in such a way as to embody a space-time structure in which no foliation by time slices, that is, smooth global spacelike hypersurfaces, is admitted. Specifically, it is the existence of space-time structures termed *closed time-like curves* in Gödelian universes which rule out the possibility of foliating these universes by a sequence of time slices.[21] I examine closed time-like curves in detail in the next section. There is, of course, no possibility in such universes of defining a privileged time slice, since no global time slices at all can be defined. This, of course, is precisely what Gödel requires if he is to argue against presentism.

We saw in the previous section that the existence of matter in a universe modelled according to the constraints of general relativity serves to restore the privileged inertial frame which was absent from universes modelled according to special relativity, and that the time slice defined by any mean motion observer as their present moment, that is, as the present moment within the privileged inertial frame, can then be interpreted as the only existing moment in the universe, thereby rendering such a universe compatible with a presentist metaphysics. However, in Gödel 1949a, Gödel indicates that it is not possible to define a privileged inertial frame in Gödelian universes, even though such universes are modelled according to the constraints of general relativity.

> "There exist cosmological solutions of another kind than those known at present, to which the aforementioned procedure of defining an absolute time is not applicable, because the local times of the special observers used above cannot be fitted together into one world time." (Gödel 1949a, p.560)

The cosmological solutions to which Gödel refers here are the solutions to the gravitational equations which Gödel had discovered and disclosed in Gödel 1949. The "special observers" to which Gödel refers are those observers "[following] in their motion the mean motion of matter" (Gödel 1949a, p. 559), which I have termed mean motion observers.

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[19] Confer Schilpp 1949.

[20] I shall henceforth refer to the rotating universes modelled by Gödel's solutions to the gravitational equations as *Gödelian universes*. Gödel went on to outline in his paper "Rotating Universes In General Relativity" (Gödel 1952) additional solutions to the gravitational equations in which the universes modeled expand as well as rotate. These may be referred to as *Gödelian expanding universes* therefore. The original solutions modeled non-expanding universes, and these may be referred to as *Gödelian non-expanding universes*, in cases where the distinction is significant.

[21] Confer Earman 1986 and Earman 1995.

Gödel gives a detailed explanation of why a privileged inertial frame cannot be defined in a Gödelian universe in Gödel 1949, his explanation there being couched in terms of the mathematics of general relativity. Rather than presenting the mathematical model which he had constructed in Gödel 1949 again, Gödel merely alludes to his mathematical results in Gödel 1949a.

> "[T]he compass of inertia [in universes defined according to Gödel's new solutions to the gravitational equations] everywhere rotates [in the same direction] relative to matter, which in our world would mean that it rotates relative to the totality of galactic systems." (Gödel 1949a, footnote 10)

In such a universe, mean motion observers, those observers following in their motion the mean motion of matter in the universe, are no longer able, because of the space-time structure of the universe, to define global time slices. Furthermore, Gödel emphasizes that, owing to the symmetry of the universes modelled by his new solutions to the gravitational equations, no particular inertial frame is privileged globally, that is, throughout the universe, but only locally, in relation to particular systems of matter within the universe.

> "[T]hese worlds possess such properties of symmetry that for each possible concept of simultaneity and succession there exist others which cannot be distinguished from it by any intrinsic properties but only by reference to individual objects, such as, e.g., a particular galactic system." (Gödel 1949a, p.560)

Thus the mean motion of matter in a Gödelian universe could no longer be used as the basis for defining a privileged time slice, although in fact no global time slices can be defined anyway.

For a presentist metaphysics, or indeed any objectively distinguished present metaphysics, to be applicable to a universe, it must be possible to identify a time slice distinguished by some global, rather than purely local, criteria from all other time slices which might be defined. This privileged time slice constitutes the only existing moment in the universe for a presentist, and thus all other time slices must be purely hypothetical, capable of being defined in theory but not existing in actuality.[22] Gödel's argument is that in the rotating universes which he has modelled, no global time slices at all can be defined.

Gödel therefore argues in 1949a that a presentist (and by implication any type of objectively distinguished present theorist) has no means of selecting a privileged global time slice to serve as the only existing moment in a Gödelian universe, since no global time slices at all can be defined in this type of rotating universe.

(f) Closed Time-Like Curves

As already indicated, it is the existence of closed time-like curves in Gödelian universes which preclude the possibility of foliating those universes by a sequence of global time slices. Gödel refers to closed time-like curves in 1949a in the course of examining the "temporal conditions" in the rotating universes which his solutions to the gravitational equations model.

(i) The Concept Of A Time-Like Curve

In Gödelian universes, it is the structure of space-time brought about by the rotation of those universes which gives rise to what Gödel terms *closed time-like curves*. Savitt speaks of a *time-like curve* as representing a "possible life history" (Savitt 1994, p.464). In other words, in the four-dimensional manifold of a static block universe, a time-like curve is a curve along which the temporal parts of a four-dimensional object could be located.

Just as the spatial parts of a metal bar are located at different locations in space, so the temporal parts of that metal bar are located at different locations in time. The first temporal part is located at the moment the bar "comes into" existence, the last temporal part is located at the moment the bar "goes out of" existence[23], and the intervening temporal parts of the bar are located at the intervening moments. The set of moments occupied by the bar, its "life history", are the time-like curve of the bar.

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[22] A growing block universe theorist allows that past as well as present time slices exist, whilst a growing determinacy theorist allows that past, present and future time slices exist, varying only in their state of determinacy. Both types of theorist nonetheless require that we be able to identify a privileged global time slice to count as the physical correlate of the present moment.

[23] Note that the bar "comes into" and "goes out of" existence only from the point of view of an observer located in time.

(ii) Open And Closed Time-Like Curves

The curvature of space-time in any universe described by the gravitational equations of general relativity depends upon the distribution and motion of matter in that universe. The behaviour of matter in the universes described by Gödel's solutions to the gravitational equations, in particular the rotation of matter in those universes, gives rise to a space-time structure in which time-like curves exist in a closed form.

As noted above, a time-like curve is a contiguous series of temporal locations along which the temporal parts of a four-dimensional object could be located. Ordinarily, we might suppose that a time-like curve would be something like the temporal equivalent of a line in space, at least to the extent that it would possess the essential topological feature of a line, namely that for any two points on the curve there would only exist one route between them along the curve. In all the solutions to the gravitational equations of general relativity which had been formulated prior to Gödel, all possible time-like curves appear to have conformed to this topology. However, Gödel had discovered that in the rotating universes modelled by his new solutions to the gravitational equations, the structure of space-time is such as to embody *closed* time-like curves, that is, curves which loop back on themselves. For any two points on a closed curve, there exist *two* routes between the points along the curve. Gödel announced his discovery of the possibility of such curves in Gödel 1949.

> "In particular, if *P*, *Q* are any two points on a world line of matter, and *P* precedes *Q* on this line, there exists a time-like line connecting *P* and *Q* on which *Q* precedes *P*." (Gödel 1949, p.447)

On a time-like curve topologically equivalent to a line in space, what we might term an *open* time-like curve, upon which some temporal ordering is assumed[24], if *P* precedes *Q* on this curve it clearly cannot be the case that *Q* precedes *P*. It could only be the case that *P* precedes *Q* *and* that *Q* precedes *P* if the curve is closed, that is, if it is topologically equivalent to a loop in space. This can be illustrated as follows, where the temporal dimension is depicted spatially, and one of the spatial dimensions is suppressed.

[24] The basis on which to assume a temporal ordering along a time-like curve is an issue to which I will return in chapters 5 and 6.

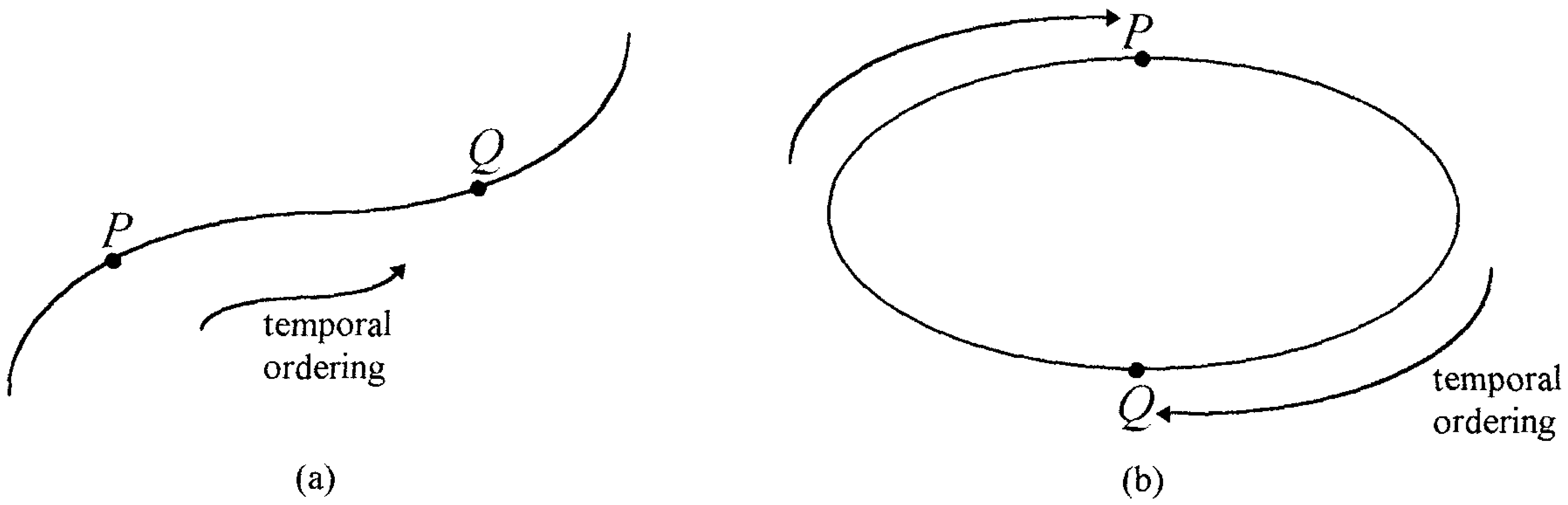

Fig. 3.1 (a) An open time-like curve on which one route exists between *P* and *Q*. (b) A closed time-like curve on which two routes exist between *P* and *Q*.

However, given that we will see that there are problems defining the direction of time around a closed time-like curve, it is useful to have a conception of a closed time-like curve which does not invoke direction. The topology of a closed time-like curve can be expressed using the pair separation relation described by Van Fraassen.[25]

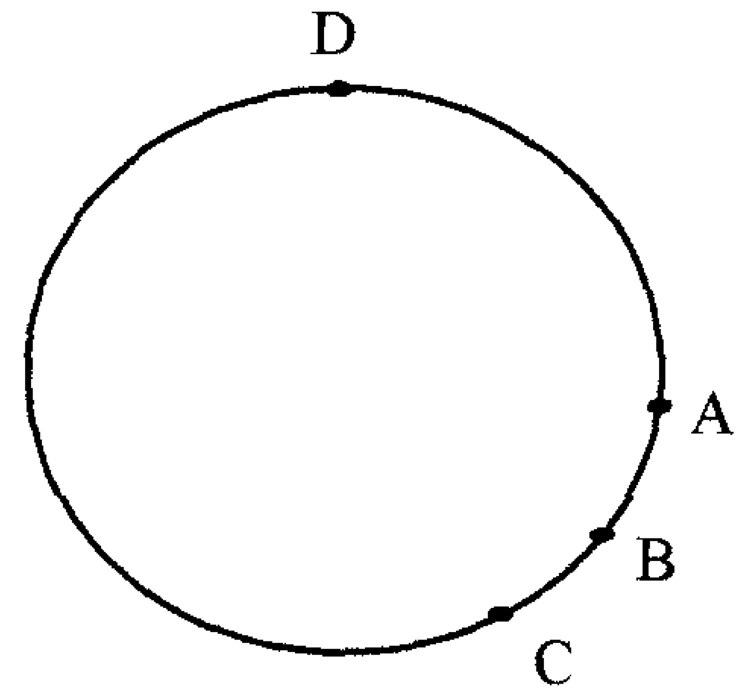

Fig. 3.2. The topology of a closed time-like curve can be defined in terms of pair separation. Diagram copied from Van Fraassen 1970, p.67.

> "But what ordering relation is more basic than before or between? The answer is: the relation of *pair separation*. On the above circle, we can say that the pair of points (*A;C*) separates the pair (*B;D*). It is clear intuitively that if you wish to go along the circle from *B* to *D*, you must pass through either *A* or *C*." (Van Fraassen 1970, p.68)

[25] The possibility of employing the pair separation relation in this context was pointed out to me by Robin Le Poidevin.

Any closed time-like curve on which four points can be defined is closed if it conforms to the definition of pair separation given above.[26]

We should note that, in a universe which conformed to a presentist metaphysics, only one point on a time-like curve, the part located at the present moment, would exist. In a static block universe, all the points on a time-like curve exist. Hence the diagrams above are more appropriate as representations of time-like curves in a static block universe than as depictions of the state of affairs in a presentist universe, where the concept of a time-like curve is necessarily a hypothetical one.

(g) Are Gödelian Universes Physically Possible?

It is the existence of closed time-like curves in Gödelian universes which rule out the foliation of those universes by a sequence of global time slices. It is impossible to define a global time slice at any point on a closed time-like curve since necessarily the curve would reintersect a global time slice, and this is not permitted.

> "Gödel's cosmological model is a dust filled universe ... The Gödel manifold M is the standard $\mathbb{R}^4$. That implies that the space-time is temporally orientable ... The space-time trajectory of each dust speck is a timelike geodesics, and each such world line is open, i.e. topologically a real line. And yet, through each event in the space-time, there is a closed, future-directed, timelike curve. It follows that the Gödel model does not contain a single global time slice! Assume for purposes of contradiction that such a slice S exists. S would be two-sided, for by definition S is spacelike and the everywhere defined, continuous, and timelike vector field which gives the temporal orientation is non-tangent to S. Pick any point x on S. There is a future directed timelike curve which departs from S in the future direction from side 1 and returns to S from side 2. Such a curve cannot get around to side 2 by intersecting S from side 1, for then temporal orientability would be contradicted. Nor can it get to side 2 by going round an 'edge' of S since S is a global time slice. And finally it cannot get to side 2 by travelling around a 'doughnut hole' in the space-time since the standard $\mathbb{R}^4$ does not have any such holes." (Earman 1986, p.172)

[26] The pair separation described by Van Fraassen is sometimes termed event pair separation. I have avoided this term in the context of closed time-like curves since describing a point on such a curve as an event may have philosophical implications which can be avoided, given that the concept of a pair is sufficient to define the topology of a closed time-like curve.

As we have seen, it is not possible to give an objectively distinguished present account of a universe which cannot be appropriately foliated by time slices. However, it is precisely the existence of closed time-like curves in Gödelian universes which lead Hawking and Ellis to doubt the physical possibility of such universes.

> "The existence of closed timelike curves in [Gödel's] solution implies that there are no imbedded three-dimensional surfaces without boundary in [the manifold] $\mathcal{M}$ which are spacelike everywhere. For a closed timelike curve which crossed such a surface would cross it an odd number of times. This would mean that the curve could not be continuously deformed to zero, since a continuous deformation can change the number of crossings only by an even number. This would contradict the fact that $\mathcal{M}$ is simply connected, being homemorphic to R^4." (Hawking and Ellis 1973, p.170)

There are, therefore, at least two ways of interpreting Gödel's results, which I will now examine.

(i) Interpreting Gödelian Universes As Physically Possible

Given that the space-time structure of Gödelian universes precludes the possibility of foliating those universes by a sequence of global time slices, it is evidently not possible to give an objectively distinguished present account of a Gödelian universe. We might conclude from this, as Gödel does, that this throws doubt upon whether it is possible to give an objectively distinguished present account of our universe, since our universe conforms to the same gravitational equations which Gödel uses to model the Gödelian universes.

It would appear that we need to interpret Gödelian universes as physically possible, in order to consider that the impossibility of giving an objectively distinguished present account of those universes has any relevance for what temporal metaphysics we are entitled to apply to our own universe. In the next chapter, I will consider Savitt's examination of the modal step which Gödel is required to make in extrapolating from Gödelian universes to our universe. As we will see, Savitt assumes that Gödelian universes are physically possible, and then goes on to question what relevance the implied temporal metaphysics of those universes has for our universe.

(ii) Interpreting Gödelian Universes As Physically Impossible

Gödelian universes are mathematical models which conform to the gravitational equations of general relativity. It is open to question whether all universes which can be modelled on the basis of the gravitational equations are physically possible, and Hawking and Ellis imply that the very fact that Gödelian universes do not admit foliation by a sequence of global time slices is evidence of their non-physicality. There is therefore a question of precedence here in relation to our theories of physics.

Gödel seems essentially to be assuming that any universe which conforms to the gravitational equations must be physically possible, whilst Hawking and Ellis imply that conforming to the gravitational equations *per se* does not guarantee physicality. If a universe which conforms to the gravitational equations conflicts with other theories of physics then we are entitled to question whether that universe is physically possible.

A defender of an objectively distinguished present temporal metaphysics can argue that the possibility of modelling universes which cannot be described in objectively distinguished present terms in no way rules out an objectively distinguished present description of our universe, if the universes which do not admit such a description are not in fact physically possible.

To some extent, it is going to be a matter of opinion whether one considers that conformity to the gravitational equations is sufficient to warrant the assumption that a particular universe is physically possible. I will do no more than indicate here that if the Gödelian universes are not physically possible, then the fact that such universes can only be described in terms of a static block universe metaphysics does not impact upon the question of what is the correct description of the temporal metaphysics of our universe.[27] In the next chapter, however, I will assume that Gödelian universes are physically possible, in order to consider whether, in that case, Gödel is entitled to draw any conclusions about the temporal metaphysics of our universe on the basis of the temporal metaphysics of the Gödelian universes.

3 Conclusion

We have seen in this chapter that Gödel argues against presentism on the basis of

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[27] If Gödelian universes are not physically possible, then our universe is certainly not a Gödelian universe. If Gödelian universes are physically possible, then it could be the case that our universe is a Gödelian universe. In that case, if a Gödelian universe is a static block universe, then our universe is a static block universe. Gödel however does not appear to be assuming that our universe is a Gödelian universe. I will therefore examine what implications the temporal metaphysics of a Gödelian universe would have for our universe in the case where our universe is not a Gödelian universe.

general relativity. In Gödel 1949a he refers to Gödelian universes which are modelled using the gravitational equations of general relativity and which do not admit foliation by a sequence of global time slices. Given that presentist and other objectively distinguished present accounts of temporal metaphysics require that a sequence of global time slices be identifiable in a universe, Gödelian universes can only be described in static block universe terms. Gödel suggests that this result may imply that our universe should also only be described in static block universe terms, since our universe conforms to the same gravitational equations which Gödel uses to model the Gödelian universes.

I have pointed out, however, that there might be other physical criteria which rule out the physical possibility of Gödelian universes. If Gödelian universes are not physically possible, then the fact that they can only be described in static block universe terms may be considered to have only limited relevance to the search for the correct description of the temporal metaphysics of our universe.

In the next chapter I will examine Savitt's analysis of Gödel's argument. Savitt accepts that Gödelian universes can only be described in static block universe terms, but questions whether it is legitimate to extrapolate from this result to the conclusion that a static block universe account is the only one which can correctly be given of any universe modelled on the gravitational equations of general relativity, including our own.

In chapter 5, I will go on to consider Einstein's response to Gödel 1949a. Einstein raises doubts about the possibility of reconciling Gödel's results with thermodynamics, suggesting an alternative reply to Gödel's argument against presentism to the one adopted by Savitt. Einstein's response indicates one possible set of those "other physical criteria" to which I have alluded in this chapter as possibly ruling out Gödelian universes as physically realizable *per se*.

4

Einstein's Field Equations And The Modal Step

1 Introduction

In his paper "The Replacement Of Time" (Savitt 1994), Savitt quotes Yourgrau's description of Gödel's 1949a paper as "beautiful and enigmatic" (Yourgrau 1991, p.1). Savitt points out that Gödel's paper, which is only nine paragraphs long, suggests "a number of different lines of argument" (Savitt 1994, p.464). Savitt therefore selects one possible line of argument suggested by the paper and sets about delineating the underlying structure of that argument. The line of argument which Savitt delineates is essentially the argument for a static block universe metaphysics on the basis of general relativity which we considered in the previous chapter.

Savitt accepts that a presentist description[1] cannot be given of a Gödelian universe for the reasons which we examined in the previous chapter. As we will see, Savitt goes on to question whether Gödel's results are applicable to the type of universe we actually inhabit, but I will begin by outlining Savitt's explication of Gödel's argument.

Savitt posits four premises on the basis of which Gödel can conclude that an objective lapse of time, what I have called existential change[2], does not occur in Gödelian universes. Savitt then suggests that Gödel can only move from the claim that existential change does not occur in Gödelian universes to the claim that existential

[1] Savitt, like Gödel, only acknowledges presentism amongst the possible physically distinguished present theories of temporal metaphysics. Savitt's argument, which constitutes a counter-argument to Gödel's argument, could in fact be employed by a growing block universe theorist or a variable determinacy universe theorist. Since Savitt focuses upon presentism, however, I shall mostly relate Savitt's argument to presentism.

[2] Confer my analysis of existential change in chapter 3, sections 2 (b) (i) and (ii).

change does not occur in *our* universe by means of what Savitt terms "the modal step".

I begin by analyzing the premises which Savitt takes to be implied by Gödel's argument, then examine the use and significance of the modal step. I consider what factors might prohibit the modal step, and whether therefore a presentist might cite such factors in defence of presentism.

2 *Savitt's Analysis Of Gödel's Argument*

Savitt states the argument which he takes Gödel to be making as follows:

"(A1) The existence of an infinity of layers of 'now' is a necessary condition for the existence of an objective lapse of time in any spacetime.

"(A2) A layer of 'now' (in a model of GTR) is a global time slice.

"(A3) There are no global time slices in *M*.

"(A4) There are no layers of 'now' in *M*.

"(A) There is no objective lapse of time in *M*." (Savitt 1994, p.465)[3]

Although Savitt's restatement of Gödel's argument helps to clarify the steps in that argument, there is a slight problem with statement (A1) in Savitt's version of the argument. (A1) appears to be a subtle rewriting of Gödel's original formulation, as becomes apparent when we compare it with Gödel's original statement which reads as follows.

> "Change becomes possible only through the lapse of time. The existence of an objective lapse of time, however, means (or, at least, is equivalent to the fact) that reality consists of an infinity of layers of 'now' which come into existence successively." (Gödel 1949a, p.558)

[3] A few notes on terminology. I sometimes refer to what Savitt, following Gödel, calls a "layer of 'now'" as a smooth global spacelike hypersurface or a time slice or a global time slice or a moment. Savitt uses "GTR" to refer to the general theory of relativity and he uses "*M*" to refer to the *four-dimensional, differentiable, temporally orientable manifold* modeled by Gödel's solutions to Einstein's field equations. A manifold is "essentially a continuous space which looks locally like Euclidean [uncurved] space" (Schutz 1990, p.151).

Note that Gödel speaks, somewhat confusingly, about the "existence" of an objective lapse of time. By his first use of "existence" in this passage I take him to mean the *occurrence* of an objective lapse of time, that is, the occurrence of what I have called existential change. He is then saying that in order for existential change to occur, *reality* must consist of an infinity of layers of "now". However, these layers must come into *existence* successively.[4] Gödel could almost be read here as describing a growing block universe in which each layer of "now" remains in existence once it has come into existence, in which case reality would consist of the present layer of "now" plus all past layers of "now". Given that he describes these layers of "now" as coming into existence, the implication is that future layers of "now", which have not yet come into existence, should not be included as components of reality.

Interpreting Gödel as describing a growing block universe here would, however, conflict with the footnote in which he speaks of "the idea of an objective lapse of time (whose essence is that only the present really exists)". A temporal metaphysics in which only the present really exists is a presentist metaphysics, and thus Gödel appears to be assuming that after a layer of "now" comes into existence it passes out of existence again, rather than accumulating to form a growing four-dimensional block.

It is perhaps not surprising, given that Gödel is arguing against an objectively distinguished present metaphysics in favour of a static block universe metaphysics, that his formulation of the objectively distinguished present position lacks clarity. However, what is clear from his description is that layers of "now" would need to "come into existence", and that it is that layer of "now" which is coming into existence which constitutes the present moment.

The problem with Savitt's statement (A1), which is supposed to represent a premise of Gödel's argument, is that it seems to imply that *all* layers of "now" must exist in order for existential change to occur. I contest however that the existence of all layers of "now" would precisely rule out an objective lapse of time, that is, existential change. Consider any two arbitrary "layers of 'now'", temporal slices, and an arbitrary physical object.[5] If both temporal slices exist, and if the same object exists in both slices, then the object is composed of at least two temporal parts, neither of which changes relative to each other, and we in fact find ourselves in a block universe of some kind, rather than one modelled according to presentism.

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[4] Gödel appears to be drawing a distinction between reality and existence in this passage. Confer my discussion of the distinction between "being real" and "existing" in chapter 2, section 2.

[5] The inclusion of a physical object is not strictly necessary, but serves to clarify the problem with Savitt's formulation of Gödel's argument.

If Savitt intends by his use, in (A1), of the phrase "an infinity of layers of 'now'" to refer only to those layers of "now" which have come into existence, that is, those layers of "now" which are past relative to the present layer of "now", then Savitt appears to be envisaging a growing block universe metaphysics of the following kind. The layer of "now" which is coming into existence constitutes the present moment, but this layer of "now" does not pass out of existence after it has come into existence. Reality therefore is cumulative, consisting of all those layers of "now" which have come into existence. An object, although composed of temporal parts, one temporal part being located in each layer of "now" in which the object exists, would undergo incremental existential change since additional temporal parts are being added to the object. If however a layer of "now" comes into existence not containing a temporal part of the object, then the end of the object's duration, that is, the end of the sequence of layers of "now" containing temporal parts of the object, has been reached.

If Savitt is assuming the growing block universe metaphysics just sketched in which layers of "now" come into but do not pass out of existence, however, I would suggest that (A1) should be reformulated as follows.

(A1*) The existence of a single present layer of 'now' and an infinity of past layers of 'now' is a necessary condition for the existence of an objective lapse of time in any space-time.[6]

We may wish to question the coherence of the concept of a "past layer of 'now'". It is not exactly clear what would distinguish any particular past layer of "now" from the present layer of "now" if both are deemed to exist. A possible distinction would be to claim that past layers of "now" exist fully, whilst the present layer of "now" is that layer of "now" which is coming into existence. On this view, a layer of "now" would cease to be the present layer of "now" when it had fully come into existence. If we adopt this approach, we may wish to equate "being real" and "existing"[7]. Reality would consist of all those layers of "now" which exist, the past layers of "now", whilst the present layer of "now" is that layer of "now" which is becoming real, that is, coming

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[6] I shall leave aside the question of whether in fact an infinity of layers of "now" would be necessary, or whether simply a finite (but probably very large) number would suffice. The question depends upon whether the universe is deemed to have a first moment of time, and whether moments are taken to be instants, that is, durationless, or intervals, that is, of finite duration. If there is a first moment of time in the universe, and each moment is an interval, then there are only a finite number of layers of "now", even though new layers of "now" are continually being added.

[7] I indicated in chapter 2, section 2, that a presentist might want to distinguish "being real" from "existing". A growing block universe theory does not appear to require such a distinction.

into existence. Past layers of "now" therefore are real and exist, the present layer of "now" is becoming real, whilst future moments are not real since they do not exist.

Although the way in which Gödel describes his version of an objectively distinguished present theory is somewhat ambiguous, and this I take it is what leads Savitt to formulate (A1) in the way he does, Gödel does nevertheless appear to be describing presentism. The metaphysics envisaged by a presentist is one in which the present layer of "now" passes out of existence after it has passed into existence. In a presentist metaphysics, therefore, past moments do not exist. As suggested previously, they could perhaps be distinguished from future moments by being deemed to be real although not existing, whilst future moments neither exist, nor are they real.[8] If Gödel is indeed describing a presentist metaphysics, then Savitt's statement (A1) is even more misleading as a requirement of such a metaphysics, and I would suggest the following replacement.

(A1**) The existence of no more than and no less than one layer of 'now' is a necessary condition for the existence of an objective lapse of time in any spacetime.

In spite of these proposed revisions to (A1), the choice between (A1*) and (A1**) depending upon whether one takes Gödel to be describing a growing block universe metaphysics or a presentist metaphysics, the rest of Savitt's argument follows as Savitt states it.

As we saw in the previous chapter, a Gödelian universe cannot be foliated by a sequence of global time slices, and this is expressed by Savitt in (A3). As a consequence, it is not possible to give an objectively distinguished present account of a Gödelian universe, since such an account requires that we be able to identify time slices, and specifically that we be able to identify a particular time slice to count as the physical correlate of what we experience as the present moment. However, as Savitt points out, in order for Gödel to draw the conclusion that it is not possible to give an objectively distinguished present account of our universe, he must either argue that we inhabit a Gödelian universe, or take what Savitt terms the "modal step" (Savitt 1994, p.465).

[8] It is in presentism, therefore that a distinction between "being real" and "existing" appears to be a useful one, providing as it does a possible means of distinguishing between past, present and future moments.

3 The Modal Step

Gödel was not apparently prepared to assert that we do inhabit a Gödelian universe. When he began writing 1949a, he had only discovered solutions to Einstein's field equations[9] which modeled non-expanding, rotating universes containing closed time-like curves, although he mentions in footnote 14 to 1949a that he has just discovered that there are solutions for "*every* value of the cosmological constant". This implies that solutions exist which model expanding rotating universes. Observational data suggests that we inhabit an expanding universe, hence Gödel's initial, non-expanding solutions do not model the type of universe we inhabit. His later, expanding solutions could potentially model the type of universe we inhabit, provided that we inhabit a rotating universe.[10]

However, Gödel implies that it does not matter whether we actually inhabit a Gödelian universe or not, that is, a universe containing closed time-like curves. He suggests that the possibility of closed time-like curves in *some* of the universes modelled by Einstein's field equations, and the concomitant impossibility of foliating such universes by a sequence of global time slices, implies that a static block universe metaphysics is the only metaphysics applicable to *all* the universes modelled by Einstein's field equations. His reasoning is apparently as follows. Universes containing closed time-like curves can be modelled on the basis of Einstein's field equations. Such universes can only be meaningfully described in static block universe terms. Therefore, all universes which can be modelled on the basis of Einstein's field equations, including our own, should be described in static block universe terms, regardless of whether or not they actually contain closed time-like curves. The latter step in this argument is what Savitt terms the modal step. Savitt expresses this step as follows.

(B) "Since there is no objective lapse of time in Gödel's model, there is no objective lapse of time in our world either." (Savitt 1994, p.464)

This is Savitt's interpretation of Gödel's original statement. I will label Gödel's statement as (B`) for purposes of reference.

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[9] I have referred to Einstein's field equations as the gravitational equations in chapter 3.

[10] It is in practice difficult to assess whether our universe rotates. The period of rotation of a Gödelian universe would be one rotation every 70 billion years, according to Gribbin 1992, p.215. Even if our universe rotates at the speed necessary for the formation of closed time-like curves, this rotation has not yet been established.

(B') "The mere compatibility with the laws of nature of worlds in which there is no distinguished absolute time, and [in which], therefore, no objective lapse of time can exist, throws some light on the meaning of time also in those worlds in which an absolute time can be defined." (Gödel 1949a, p.562)

Savitt seems to state Gödel's position rather more definitely than Gödel himself does. In order to assess Gödel's argument, either in the highly compressed form provided by Gödel himself, or in the form of Savitt's interpretation, it is useful to recognize that there is a crucial assumption contained in the underlying argument.

A proponent of the modal step is required to decide whether a temporal metaphysics is necessarily true, that is, true of all physically[11] possible universes if it is true of one physically possible universe. It can be argued that if one possible universe can only be described in, for example, static block universe terms then it must be the case that all possible universes, including our own actually existing universe, can only be described in static block universe terms. This assumption, that it cannot simply be a contingent matter as to whether a universe is either a static block universe or a universe in which the present moment is objectively distinguished, must underlie Gödel's recourse to the modal step.

There are at least two possible responses to this assumption. Firstly, the fact that a static block universe may be physically possible does not, *prima facie*, seem to carry the implication that all possible universes must therefore be static block universes. Why should it not be the case that some physically possible universes are static block universes whilst other physically possible universes conform to some version of an objectively distinguished present theory? The question here seems to be the degree of necessity one is prepared to allocate to one's temporal metaphysics.

It may be that the contrast between a static block universe and a universe in which only the present moment exists is so great that it is difficult to believe that if one physically possible universe can only be described in terms of a static block universe metaphysics, another physically possible universe could still be described in terms of a presentist metaphysics. However, the contrast between a static block universe and a growing determinacy universe is not so great, and the fact that one physically possible universe is a static block universe does not seem to rule out the possibility that another

[11] It is clearly the case that both static block universes and physically distinguished present universes are logically possible. We will therefore be concerned with physically possible universes, in relation to the question of necessity.

physically possible universe should be a growing determinacy universe. The only difference between the universes would be that, whereas the determinacy of moments of time does not vary in the static block universe, it does vary in the growing determinacy universe. It is not, therefore, self evident that establishing the temporal metaphysics of one physically possible universe makes it necessary that all physically possible universes should conform to the same temporal metaphysics. The degree of necessity will, I believe, depend upon just how different one takes one's available temporal metaphysics to be.

Nonetheless, we should still observe that, if it is considered that a temporal metaphysics must be necessarily true, that is, true of all possible universes if it is true of one possible universe, then a defender of an objectively distinguished present temporal metaphysics is required to argue that Gödelian universes cannot be physically possible since they are only describable in static block universe terms.

As we saw in the previous chapter, Gödel demonstrates that Gödelian universes are only describable as static block universes. If we combine this result with the assumption that the temporal metaphysics of one physically possible universe is necessarily the temporal metaphysics of all possible universes, and the assumption that Gödelian universes are physically possible, we arrive at the conclusion that it is necessarily the case that we ourselves inhabit a static block universe.

Gödel allows the defender of a presentist (or some other objectively distinguished present) metaphysics a response to this claim. The presentist, according to Gödel, can assert that existential change occurs, but only if the presentist is prepared to claim that whether or not such change occurs "depends on the particular way in which matter and its motion are arranged in the world" (Gödel 1949a, p.562). This would clearly conflict with the assumption that the static block universe metaphysics of some physically possible universes, the Gödelian universes, is necessarily the temporal metaphysics of all physically possible universes, always assuming that the Gödelian universes are in fact physically possible. Given that Gödel evidently assumes that Gödelian universes *are* physically possible, he is dismissive of any attempt to defend an objectively distinguished present account of the temporal metaphysics of our universe on such contingent grounds as the arrangement and motion of matter in our universe.

Although Gödel appears to rely on the assumption that if a temporal metaphysics is true of one physically possible universe, it must be true of all physically possible universes, it is possible to reconstruct a slightly different, although closely related argument which does not rely on the assumption that a temporal metaphysics is necessarily true or necessarily false of all possible universes. We can, I propose, reconstruct the following line of reasoning.[12] First of all, I shall suggest what I take Gödel to mean by "laws of nature", the term which he uses in his statement (B`), and the relation between laws of nature and contingent features of a universe.[13]

(L1) A law of nature relates a property of a constituent or constituents of a universe to another property of a constituent or constituents of a universe.[14]

(L2) Contingent properties of a universe do not alter the relationship between the properties of constituents of a universe, where that relationship is described by a law of nature.

A simple example, unrelated to Gödel's argument, may serve to clarify these premises. Consider the posited law of nature, "All metals expand when heated".[15] This law relates the property "is a metal" to the property "expands when heated". So if constituent X of a universe is a metal, then constituent X expands when heated. (L1) attempts to summarize the fact that a law of nature describes a relationship between properties of constituents of a universe. I speak of a "constituent" in order to keep the definition of a law as general as possible.

Suppose now that constituent X of a universe, which has the property "is a metal", also has the property "is cylindrical". If the shape of X is a contingent property, then (L2) implies that the cylindrical shape of X will not alter the fact that X expands when heated. Notice that this analysis may imply that laws of nature should be interpreted as expressing relationships between non-contingent, that is, necessary, properties of a constituent of a universe. I will not attempt to establish whether this interpretation is valid for all laws of nature, but will refer back to this possible interpretation in the course of the analysis of Gödel's argument.

We can now analyze how precisely Gödel's concept of a law of nature impacts

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[12] I am not suggesting that Gödel necessarily followed this line of reasoning in drawing his conclusion. Nonetheless, the line of reasoning proposed serves to make sense of his conclusion.

[13] I shall label the steps in the proposed argument (L1), (L2) and so on. I use an "L" prefix since the argument depends upon Gödel's concept of a law of nature.

[14] (L1) is formulated so as to accommodate laws of the form $(\forall x)(\exists y)(Fx \rightarrow Gy)$, for example, as well as simpler laws of the form $(\forall x)(Fx \rightarrow Gx)$.

[15] I will leave aside epistemological questions, such as whether we can be certain that a generalization which supposedly applies to all possible instances of heating metals, both observed and unobserved, is true in some correspondence sense of the word "true", and if we cannot be certain, as appears to be the case, what it then means to call such a generalization a law.

upon his interpretation of Einstein's field equations. I attribute the following assumptions to Gödel.

(L3) Einstein's field equations are "laws of nature".

(L4) (L1) and (L3) together imply that Einstein's field equations relate a property of a constituent of a universe described by the field equations to another property of that same constituent.

(L5) (L2) and (L3) together imply that the relationship described by Einstein's field equations is not determined by contingent properties of a universe described by the field equations.

(L6) The amount, distribution and motion of matter in a universe described by Einstein's field equations are contingent properties of such a universe.

(L7) (L5) and (L6) together imply that the relationship described by Einstein's field equations is not determined by the amount, distribution and motion of matter in a universe described by the field equations.

Let us consider in turn each component of the argument which I am attributing to Gödel. I conclude that Gödel holds (L3) since I take it that he is obliquely referring to Einstein's field equations when he uses the term "laws of nature" in (B`). (L4) and (L5) then follow from the interpretation of laws of nature which I attribute to Gödel in (L1) and (L2). I deduce (L6) from Gödel's claim that a presentist can only assert that existential change occurs if the presentist is prepared to claim that whether or not such change occurs "depends on the particular way in which matter and its motion are arranged in the world" (Gödel 1949a, p.562). I take this statement to imply that Gödel considers the "way in which matter and its motion are arranged", what I have described as the amount, distribution and motion of matter, to be contingent properties of a universe. (L7) then follows from (L5) and (L6).

What we now need to consider is whether Gödel is justified in conceiving of Einstein's field equations as laws of nature, and how his conception of the field equations relates to his application of the modal step. The first point to ascertain is whether the field equations conform to the description of a law of nature which I suggest in (L1). The field equations can be expressed mathematically as follows.[16]

$$R_{ik} - \frac{1}{2} g_{ik} R = T_{ik} - \Lambda g_{ik}$$

As such, the field equations express a relationship between the curvature of space-time (the manifold referred to in footnote 3, this chapter), its geometric properties, as denoted by the Ricci tensor R_{ik}, where R is the scalar curvature, and the distribution and motion of matter and energy[17] as denoted by the stress-energy tensor T_{ik}.[18] I have suggested in (L1) that a law of nature relates a property of a constituent of a universe to another property of that same constituent. The field equations relate one property, the curvature of space-time, to another property, the distribution and motion of matter and energy. The question arises as to whether these are properties of the same constituent of a universe, and if so, what that constituent is. In fact, it appears that they are properties of regions of a universe, where a region is defined both spatially and temporally, such that if, for example, we knew the distribution and motion of matter and energy in that region, we would be able to calculate the curvature of space-time in that region. Since a region of a universe is undoubtedly a constituent part of that universe, the field equations appear to conform to the definition of a law of nature which I propose in (L1). Gödel is therefore entitled to conceive of the field equations as laws of nature, at least if he conceives of a law of nature along the lines described in (L1).

According to (L7), the relationship expressed by Einstein's field equations should not be affected by the distribution and motion of matter in a universe. We can see that, according to the field equations, as the distribution and motion of matter vary, so the curvature of space-time will vary. However, provided that the variation in curvature relative to the variation in the distribution and motion of matter conforms to the relationship expressed by the field equations, then the distribution and motion of matter cannot be said to have changed the relationship expressed by the field equations. Provided that this condition is met, the field equations can be said to satisfy (L7).

I have attempted to reconstruct in (L1) to (L7) a set of assumptions which I believe Gödel requires in order for him to argue that the possibility of the existence of

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[16] This is only one possible representation of Einstein's field equations, the representation which Gödel himself used in Gödel 1952. As Gödel notes, he is assuming the use of measuring units which make $c=1$, $8\pi k/c^2=1$. An accessible discussion of Einstein's field equations can be found in Schutz 1990, chapter 8.

[17] Recall that matter can be converted into energy, and vice versa, in relativistic physics.

[18] The other components of the field equations, the metric g_{ik} and the cosmological constant Λ, are not essential to the analysis of Gödel's argument. See Schutz 1990, chapter 8 for an account of them.

universes in which existential change does not occur "throws some light", as he puts it in (B`), on universes such as our own, where we might have concluded that existential change does occur. As we have seen, Savitt states rather more positively than Gödel what light the possibility of the existence of universes in which existential change does not occur might be conceived of as throwing on our own universe, in his statement of the modal step. I will repeat Savitt's statement here for ease of reference.

(B) "Since there is no objective lapse of time in Gödel's model, there is no objective lapse of time in our world either." (Savitt 1994, p.464)

A line of reasoning which leads to the formulation of the modal step as given by Savitt can be reconstructed as follows.[19]

(B′1) Gödelian universes conform to Einstein's field equations.

(B′2) In Gödelian universes, there is no objective lapse of time.

(B′3) It is because Gödelian universes conform to Einstein's field equations that no objective lapse of time occurs in them.

(B′4) Our world conforms to Einstein's field equations.

(B′5) Since our world conforms to Einstein's field equations, there is no objective lapse of time in our world.

Since the second half of (B′5) follows from (B′2), by means of (B′3) and (B′4), we can in effect state that "(B′2) implies the second half of (B′5)", which amounts to Savitt's modal step, (B). I believe, as Savitt implies, that (B) is essentially the conclusion at which Gödel was gesturing in his statement of (B′). I now want to consider why Gödel requires (L1) to (L7) in order to arrive at (B′), and also to suggest

[19] Note that Savitt describes the actual line of reasoning which led him to his formulation of (B) (Savitt 1994, p.468). This is not the line of reasoning which I describe here. My aim however is not to assess the details of Savitt's argument, but rather to reconstruct the assumptions and line of reasoning which might have led Gödel to his statement of (B`). As such, the line of reasoning which I describe here, and which I denote by the steps (B`1), (B`2), and so on, encapsulates the main points of Savitt's actual line of reasoning.

that a further essential assumption is implicit in the statement (B′3). The most convenient way in which to perform this analysis of Gödel's argument will be by considering how a defender of an objectively distinguished present theory might respond to the invocation of the modal step. I will consider the response which might be made by a presentist, since presentism is the type of objectively distinguished present theory at which Gödel addresses his argument. In fact, exactly the same response as that made by a presentist could be made by a growing block universe theorist or a growing determinacy universe theorist, the only difference being that they would be defending somewhat different concepts of objective change.

4 Presentist Responses To The Modal Step

The modal step can be challenged in a variety of ways. Savitt suggests that a "blunt challenge" (Savitt 1994, p.466) can be made. An opponent of the modal step, Savitt avers, is entitled to state the following.

> "[W]hile there is no objective lapse of time in the Gödel model because of its peculiar topological structures, there is objectively lapsing time here in our differently abled world." (Savitt 1994, p.466)

It might initially appear that a defender of the modal step wishing to respond to this claim could simply restate Gödel's original complaint that the presentist can only cite contingent features of the universe we actually inhabit to justify the claim that time "lapses objectively", that is, that existential change occurs.

The Gödelian argument is as follows. Our universe could only be "differently abled" to Gödelian universes in contingent ways. Nonetheless, the universe we inhabit conforms to the same field equations as those on the basis of which Gödelian universes can be modelled. Given that existential change is ruled out in Gödelian universes, it should also be ruled out in any universes, including our own, which conform to the same field equations as those on the basis of which Gödelian universes can be modelled.

Notice that according to this argument, it is not being claimed that it is the presence of the distinctive feature of Gödelian universes, closed time-like curves, in our universe which rules out existential change, unless our universe in fact contains closed time-like curves, which is not Gödel's claim. If existential change is ruled out in our universe it must be because our universe, like Gödelian universes, conforms to Einstein's field equations. It is important to note, therefore, that the Gödelian claim is that it is conformity to Einstein's field equations which precludes existential change in our universe, rather than the existence of those "peculiar topological structures" to which Einstein's field equations can give rise. The importance attached to Einstein's field equations embodies the assumption that if a temporal metaphysics is true of one physically possible universe, it must be true of all physically possible universes, that is, it must be necessarily true. The conformity of Gödelian universes to Einstein's field equations at once implies that they are physically possible, as far as Gödel is concerned, and links them to our own universe which also conforms to Einstein's field equations.

The modal step can indeed be justified if conformity to Einstein's field equations is construed as precluding existential change. In that case, existential change is ruled out in any universe which conforms to the field equations, including our own. However, the "blunt challenge" is not as blunt as it first appears in that case, since explicitly stated in the challenge is the claim that it is the existence of "peculiar topological structures" in the Gödelian universes, rather than conformity to the field equations used to model such universes, which precludes existential change.

If it is the existence of "peculiar topological structures" which rules out existential change, rather than conformity to Einstein's field equations, then it is more difficult to justify the modal step. Crucially, the topological structures characteristic of Gödelian universes, the closed time-like curves, appear to be contingent. The existence of closed time-like curves "depends on the particular way in which matter and its motion are arranged in the world" (Gödel 1949a, p.562) just as much as the non-existence of such structures. But it is precisely the arrangement and motion of matter which Gödel identifies as a contingent feature of a universe. Therefore whether or not closed time-like curves exist would appear to depend upon a feature of universes, the arrangement and motion of matter within them, which Gödel himself identifies as contingent.

Let us consider again what Gödel has actually shown us. He has shown that some of the universes which can be modelled on the basis of Einstein's field equations contain closed time-like curves. It is apparent, however, that not all universes which can be modelled on the basis of the field equations contain such structures. So whilst closed time-like curves do rule out existential change, since they preclude the possibility of foliating a universe into a sequence of global time slices, this in itself is not sufficient to demonstrate that existential change is ruled out in all the universes which can be modelled on the basis of Einstein's field equations. We are not entitled to conclude that existential change is ruled out in all those universes which do *not* contain closed time-like curves, unless we make the more substantial claim that existential change is precluded in any universe which conforms to Einstein's field equations, simply because that universe *does* conform to the field equations. This would amount to the claim that Einstein's field equations themselves preclude existential change.

In order to take the modal step which Savitt describes, therefore, a Gödelian has to assume that Einstein's field equations themselves rule out a presentist metaphysics, rather than the topological structures to which they give rise in Gödelian universes. Gödel seems in effect to be arguing that his Gödelian universes simply make explicit what is already implicit in Einstein's field equations, namely that the field equations are incompatible with presentism. It is certainly possible to interpret the field equations in this way. An advocate of a static block universe metaphysics might argue, for example, that the temporal dimension is effectively interchangeable with the three spatial dimensions in the type of universes which the field equations model, that this interchangeability is perfectly consistent with a static block universe metaphysics, but inexplicable in presentist terms, and that Gödelian universes merely illustrate, in the form of closed time-like curves, one rather dramatic consequence of this interchangeability.

However, a counter-argument to the Gödelian line presents itself at this point. A defender of presentism can retort that the field equations appear to be neutral in respect to the type of temporal metaphysics which they permit. They can certainly be used to model Gödelian universes which contain structures which rule out the possibility of existential change. They can also be used, however, to model universes which do not contain such structures and which may therefore be compatible in principle with existential change. This line of argument embodies the claim that Einstein's field equations are not intrinsically incompatible with a presentist metaphysics, even though some of the universes which can be modelled on the basis of the equations may be. Once again, we are returned to the question of whether, if one physically possible universe can only be described in terms of a static block metaphysics, then necessarily all physically possible universes should be described in such terms.

The defender of presentism can continue by pointing out that no topological structures have been shown to exist in our universe which are incompatible with presentism, at least as yet, so that a presentist metaphysics cannot be ruled out as the correct account of our universe, even though our universe conforms to Einstein's field equations.

We can, on reflection, observe that (B'3)[20] embodies the assumption that it is Einstein's field equations themselves which preclude existential change, rather than some of the topological structures to which the field equations give rise. As we have seen, this assumption is open to question.

I contend that Gödel's implicit assumption of (B'3) arises out of his conception of Einstein's field equations as laws of nature. (L1) to (L7) are the assumptions which underline his conception of the field equations as laws of nature, and (L2), (L5), (L6) and (L7) in particular explain his belief that the presentist would have to cite contingent facts about the distribution and motion of matter in a universe to justify the claim that existential change occurs. The fact which Gödel does not appear to have considered is that those topological structures which preclude existential change, the closed time-like curves, are themselves contingent. It is only by assuming, as Gödel apparently does, that existential change is precluded in *any* universe modelled on the basis of Einstein's field equations, whether or not that universe contains closed time-like curves, that the modal step can be justified. This amounts to the assumption that it is the field equations themselves which preclude existential change, rather than some of the topological structures to which they give rise. This assumption is nowhere justified by Gödel, and is thus open to challenge by a defender of presentism.

5 Einstein's Field Equations As The Source Of Temporal Metaphysics

We have seen in this chapter that, although Gödelian universes can only be described in static block universe terms, a number of additional assumptions are required in order to draw the conclusion towards which Gödel points us, namely that our universe can only be described in static block universe terms. Assuming that our universe is not a Gödelian universe[21], Gödel needs to assume that if a temporal metaphysics is true of one physically possible universe, then it is necessarily true, that is, it is true of all physically possible universes. He needs to assume in addition that Gödelian universes are physically possible.

It is in fact possible to reach the conclusion that our universe can only be described in static block universe terms without assuming that a temporal metaphysics true of one physically possible universe is necessarily true of all physically possible

[20] Recall that (B'3) consisted of the following statement. "It is because Gödelian universes conform to Einstein's field equations that no objective lapse of time occurs in them."

[21] If our universe is a Gödelian universe, then a physically distinguished present account cannot be given of our universe. In that case, no additional assumptions are required in relation to our universe. Gödel nowhere claims, however, that our universe is a Gödelian universe.

universes. Gödel could assume that Einstein's field equations themselves preclude existential change, rather than the structures to which they give rise. In that case it is possible to argue that it is the conformity of our universe to the field equations which precludes existential change. It is however difficult to motivate this assumption.

If we assume that the temporal metaphysics true of one physically possible universe is not necessarily true of all physically possible universes, then the physical possibility of Gödelian universes does not pose a serious problem for advocates of an objectively distinguished present account of our own universe. It seems that we could concede that there are possible worlds in which time does not flow, and perhaps even concede that "flowing" and "static" worlds could conform to the same field equations, without having to concede that "flowing" worlds are impossible. In that case, Gödel would have to show that our universe was in fact a Gödelian universe, in order to claim that our universe was a static block universe.

If however it is considered that, in the case where we are constrained to accept a static block universe temporal metaphysics as the description of a physically possible universe, we are thereby constrained to accept the same temporal metaphysics as the description of any physically possible universe, then the physical possibility of Gödelian universes would appear to rule out the possibility of describing our own universe in anything other than static block universe terms. The question therefore arises as to whether Gödelian universes are in fact physically possible.

I will begin the next chapter, therefore, by examining Einstein's thoughts on the physical possibility of closed time-like curves in the Gödelian universes modelled on the basis of Einstein's field equations.

5

Thermodynamics And The Direction Of Time

1 Introduction

We saw in the previous chapter that an advocate of a static block universe temporal metaphysics can argue, on the basis of the claim that a physically distinguished present metaphysics is not a coherent description of Gödelian universes, that a physically distinguished present metaphysics is not a coherent description of our universe. Such a theorist is described by Savitt as taking what he terms the modal step.

We saw that the modal step can be motivated if we assume the following.

(i) All physically possible universes must be described in terms of the same temporal metaphysics. Therefore, if it turns out that one physically possible universe can only be described in terms of one particular temporal metaphysics, then all other physically possible universes must be described in terms of that metaphysics. In other words, a temporal metaphysics is necessarily true or necessarily false, true in all possible universes or false in all possible universes.

(ii) Gödelian universes are physically possible universes.

If we combine these two assumptions with the observation that Gödelian universes can only be described in terms of a static block universe temporal metaphysics, then we arrive at the conclusion that our own universe must also be a static block universe.

I considered in the previous chapter whether it might be possible to challenge assumption (i), depending upon what one assumes would constrain time to have a particular physical realisation in different physically possible universes. However, I shall for now assume that (i) is the case, and therefore consider whether we have to accept assumption (ii).

Evidence that we should perhaps not accept assumption (ii) arises out of a short response to Gödel 1949a made by Einstein, in which Einstein in effect questions whether entropy could vary in a Gödelian universe in the way it would have to in order for that universe to conform to the second law of thermodynamics. As we will see, it does not appear that Gödelian universes can conform to the second law, and this leads me to question therefore whether it is legitimate to treat Gödelian universes as physically possible. I will go on to examine the larger question which Einstein's response to Gödel suggests, namely whether in general a Gödelian universe would have to conform to all the laws of physics in order for it to be physically possible.

I will then demonstrate that, if we assume that the second law of thermodynamics applies to the universe as a whole, it is possible to give an objectively distinguished present account of any universe which conforms to the second law of thermodynamics.

2 Einstein's Response To Gödel's Rotating Universes

Gödel was prompted to write 1949a when he was asked for a contribution to a volume[1] of collected papers in honour of Einstein. Fortunately Einstein was given the opportunity to reply to the various papers written in his honour, and amongst his replies was a brief response to Gödel 1949a, which I will refer to as Einstein 1949.[2]

(a) A Method Of Establishing The Temporal Orientation Of A Time-Like Curve

In his reply to Gödel's paper, Einstein invites us to consider the situation depicted in figure 5.1. This figure, which reproduces the diagram employed by Einstein, shows the light cones associated with an arbitrary space-time[3] point *P*. A time-like curve[4] is shown passing through *P*, on which the space-time points *A* and *B*, also arbitrary, are located, separated by *P*. Einstein asks, in relation to this situation, whether it is possible to assign a direction to the time-like curve passing through *P*, enabling us to specify, for

[1] Schilpp 1949.
[2] Confer Schilpp 1949, pp.687-688.
[3] Einstein refers to a space-time point as a "world-point".
[4] Einstein refers to a curve as a "world-line".

example, that *B* is before *P* and that *A* is after *P*.

> "Does it make any sense to provide the world-line with an arrow, and to assert that *B* is before *P*, *A* after *P*?" (Einstein 1949, p.687)

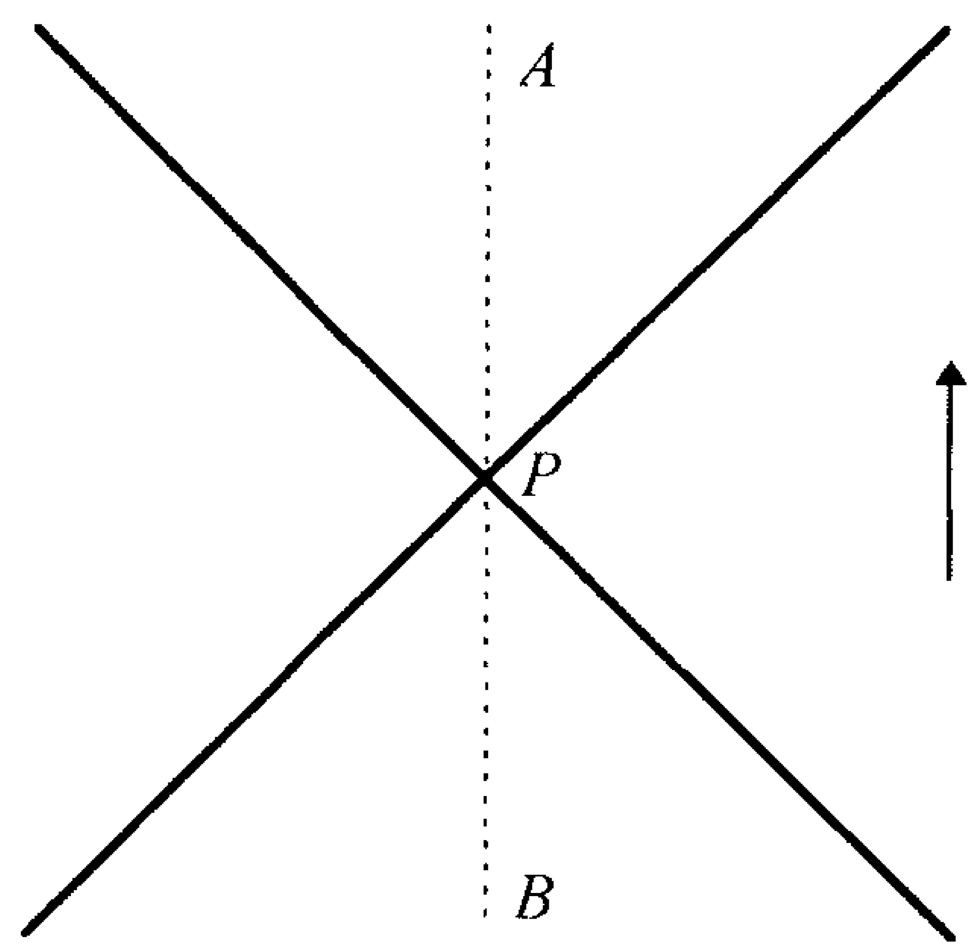


Fig. 5.1 Light cones, shown as solid lines, belonging to a space-time point *P*, and a time-like curve, shown as a dotted line, passing through *P*. The space-time point *P* separates two other space-time points *B* and *A*. The up arrow to the right of *P* indicates a postulated direction of time. Reproduced from Einstein 1949, p.687.

Einstein is alluding in this question to a feature of the general theory of relativity which, he reveals, had disturbed him even whilst he was constructing the theory. Einstein is unsure whether the general theory of relativity embodies within it any mechanism for establishing a direction of time.

> "Is what remains of temporal connection between world-points in the theory of relativity an asymmetrical relation, or would one be just as much justified, from the physical point of view, to indicate the arrow in the opposite direction and to assert that *A* is before *P*, *B* after *P*?" (Ibid.)

Einstein goes on to imply that if one wishes to assign a temporal orientation to a time-like curve, one must import some mechanism for establishing such a temporal orientation from another branch of physics. He proposes a method of assigning a temporal orientation to a time-like curve which involves the sending of what Einstein terms a "signal".[5] He suggests that if a signal can be sent from B to A, but not from A to B, this implies that B is before A. The arrow indicating a temporal progression from earlier (the tail of the arrow) to later (the head of the arrow) is then as illustrated in figure 5.1. Furthermore, if the signal can only be sent in one direction the time-like curve *has* to be assigned the orientation indicated by the arrow.

> "If it is possible to send (to telegraph) a signal (also passing by in the close proximity of P) from B to A, but not from A to B, then the one-sided (asymmetrical) character of time is secured, i.e., there exists no free choice for the direction of the arrow." (Ibid.)

If we find, therefore, that we can only send signals in one direction along time-like curves, we are provided with a method of assigning a temporal orientation to such curves. We need to ask, therefore, whether in fact there is any restriction upon the direction in which can we send signals along time-like curves. What is to stop us, for example, in the situation we are considering, from sending a signal from A to B? Einstein implies that there is nothing in general relativity itself which indicates any restriction upon the direction in which signals can be sent along time-like curves. It is only if we look outside of relativity theory, Einstein suggests to thermodynamics, that we find constraints upon the direction in which we can send signals. As Einstein points out, in terms of thermodynamics, the sending of a signal is an irreversible process.

> "[T]he sending of a signal is, in the sense of thermodynamics, an irreversible process, a process which is connected with the growth of entropy." (Einstein 1949, pp.687-688)

We need to consider why, precisely, this is the case, by considering the second law of thermodynamics, the law which specifically relates to entropy. Before doing so, let us establish the significance of Einstein's comment in the context in which he makes it. Let us assume for now that the sending of a signal is indeed irreversible. In that case,

[5] Einstein does not elaborate upon what he means by a signal, although he does qualify the "sending" of the signal as its "telegraphing". He may be envisaging the transmission and reception of a pulse of electromagnetic energy, but presumably any means of transmitting and receiving a signal of any kind would suffice. Use of the word "signal" does however imply that the act of transmitting is intentional. Thus detecting electromagnetic radiation from a star would not constitute detecting a signal, whilst detecting electromagnetic radiation from a radio station would.

if we know that a signal was sent from some space-time point B and received at some space-time point A, where B and A are located on the same time-like curve, then we can conclude that B is before A, and thus that the time-like curve has a temporal orientation. Clearly, in the case described, a signal could not be sent from A and received at B, since this would amount to reversing a process, the sending of a signal, which the second law of thermodynamics implies is irreversible. Einstein is therefore proposing a method of establishing the temporal orientation of a time-like curve based upon signalling, a method that is which relies upon thermodynamics rather than upon relativity theory.

(b) Entropy And The Second Law Of Thermodynamics

Let us now consider why the second law of thermodynamics implies that the sending of a signal is an irreversible process. As Coveney and Highfield (1990) note, there are a variety of different ways of formulating the second law.

> "The American philosopher David Hull[6] has recently pointed out that physicists can readily compile a list of 20 or more different formulations of the Second Law." (Coveney and Highfield 1990, p.148)

A formulation of the second law of thermodynamics which will serve to illuminate Einstein's reference to the law in his response to Gödel is as follows.

> "The only changes that are possible for an isolated[7] system are those in which the entropy of the system either increases or remains the same. Changes in which the entropy decreases will not happen." (Halliday and Resnick 1988, p.525)

Just as there are various formulations of the second law of thermodynamics, so there are various definitions of entropy. The following definition is the one usually used in thermodynamics.

$$dS = \frac{dQ}{T}$$

[6] Confer Weber, Depew and Smith 1988, p.3.

[7] I will discuss shortly the significance of the description of the system as "isolated".

It is stated in the second law of thermodynamics that the entropy of an isolated system will either increase or stay the same over time. In fact, entropy only remains the same if a physical process is reversible, and all the empirical evidence points to it being the case that no physical processes are truly reversible. Therefore the second law of thermodynamics tells us in effect that the entropy of an isolated system will always increase over time.

The reason that the second law is formulated in terms of an isolated system, as opposed to a closed or open system, is that it is possible to lower the entropy of a closed or open system over time.[8] This is possible by transferring energy or matter from or to the spatial region surrounding the closed or open system, thereby increasing entropy in the surroundings by a greater amount than the amount by which entropy is decreased in the closed or open system. Therefore the second law only applies to isolated systems.[9]

It is in practice virtually impossible to construct a perfectly isolated system, and usually the concept of an isolated system is used as an idealization in thermodynamics. However, our universe appears to be the one actually existing example of a perfectly isolated system, assuming that we define a universe as everything that exists. If the universe is everything that exists, then it cannot have any surroundings. In general, we can see that any possible universe constitutes a perfectly isolated system.[10]

(c) The Paradox Of Entropy Increase Along A Closed Time-Like Curve

We now have the conceptual tools necessary to understand why Einstein refers to the sending of a signal as an irreversible process.[11] In order to send a signal, a degree of order will need to be imposed in the spatial region designated as point B, where B is some arbitrary point on a time-like curve. In order to impose the ordering necessary to send the signal, energy or matter will have to be transferred to or from the surroundings

[8] An isolated system is defined thermodynamically as one which has no contact with its surroundings. Thus no matter or energy can enter or leave an isolated system. A closed system is defined as one which can exchange energy with its surroundings, but cannot exchange matter. An open system is defined as one which can exchange both energy and matter with its surroundings.

[9] As Coveney and Highfield 1990 indicate, in a section entitled "Order Out Of Chaos" (pp.159-162), closed and open systems can change over time from less ordered states into more ordered states. The second law of thermodynamics should not therefore be interpreted as implying a straightforward descent of all systems in the universe from order into chaos.

[10] In 1865, Rudolf Clausius formulated the first two laws of thermodynamics in cosmological terms, after recognizing that the universe is a perfectly isolated system. In cosmological terms, the first law states that the total energy of the universe is constant, and the second law states that the total entropy of the universe is increasing. Confer Clausius 1867, Coveney and Highfield 1990, p.153.

[11] Unfortunately, Einstein's reply to Gödel is very brief and he does not elaborate on what he means here.

of point B.[12] The net effect of the transfer of energy or matter will be to raise the entropy of the surroundings of point B by a greater amount than the entropy is lowered at point B itself. Sending a signal from point B will therefore have the effect of raising the entropy of the universe as a whole, since, as we have seen, the universe can be considered as a perfectly isolated system.

According to the second law of thermodynamics, the entropy of an isolated system can only stay the same or increase over time. Since the process of sending a signal increases the entropy of the universe, which constitutes an isolated system, signals can only be sent forwards through time. A signal could only be sent backwards through time if the process of sending a signal decreased entropy in the universe as a whole, and it is difficult to see how this could occur since the process of sending a signal requires that we decrease entropy in a localized region of the universe, and such a decrease appears invariably to require that we increase entropy elsewhere in the universe by a larger amount. Thus the arbitrary point A on a time-like curve, at which a signal sent from the arbitrary point B on the same time-like curve is received, must lie after B, since the receiving of a signal can only lie in the future of the sending of a signal. This is why the sending and receiving of a signal can be used to establish the temporal orientation of a time-like curve.

As we have noted, it had already occurred to Einstein when he was formulating the general theory of relativity that the space-times modelled by the theory might lack a temporal orientation. However, it is specifically in response to Gödel's paper on the possibility of universes containing closed time-like curves that Einstein proposes a method of establishing the temporal orientation of time-like curves *per se* by means of sending and receiving signals. What is it about closed time-like curves which prompts Einstein to raise the issue of temporal orientation? In fact, it can be demonstrated that if we assume that time-like curves have a temporal orientation, and that entropy always increases along a time-like curve as we move from earlier to later points on the curve, then a closed time-like curve presents us with a paradox.

Consider a small closed thermodynamic system[13] (a gas in a box, for example) located at some arbitrary point P_1 on a closed time-like curve. I will suppose that this closed thermodynamic system has an arbitrary entropy S_1. That is, S_1 is the entropy of the system at the moment of time associated with P_1.

[12] Note that point B is most likely to constitute an open system, although there is nothing to prohibit it constituting a closed system.

I am associating a point on the curve with the entropy of a small closed system since a point in a space-time diagram indicates the space-time location of a particular small object, that is, one that can be represented as a point mass. Although in practice it is impossible to construct a perfectly isolated thermodynamic system, for the purpose of illustration it is sufficient to consider a closed thermodynamic system located on the curve.

Although local entropy can decrease as well as increase, I will assume that since the thermodynamic system is closed, it will obey the second law of thermodynamics perfectly and hence its entropy will increase over time.

Suppose we establish that P_2 lies after P_1, by means of Einstein's signaling technique. Then we can infer that P_2 is associated with an entropy S_2, where S_2 is defined as follows.

$$S_2 = S_1 + \Delta S$$

ΔS is a positive arbitrary increment in entropy. We can see from this formulation that P_2 is associated with a higher entropy than P_1.

Similarly, suppose we establish that P_3 lies after P_2, by means of the signaling technique. Then we can infer that P_3 is associated with an entropy S_3, where S_3 is defined as follows.

$$S_3 = S_2 + \Delta S = S_1 + 2\Delta S$$

For convenience, I shall define P_3 such that the same increase in entropy, ΔS, occurs between P_2 and P_3 as occurs between P_1 and P_2.

We can continue to associate entropy values with points along the time-like curve in this fashion. Because, however, the time-like curve is closed, we will in theory eventually reach an arbitrary point P_n, associated with an entropy S_n, located a short time *before* P_1, the point from which we started. We should be able to infer that P_1 is associated with an entropy S_{n+1}, where S_{n+1} is defined as follows.

$$S_{n+1} = S_n + \Delta S = S_1 + n\Delta S$$

[13] The use of a small closed thermodynamic system in this thought experiment was suggested to me by Roman Frigg.

This inference however clearly conflicts with the original assumption that the point P_1 is associated with the entropy S_1. Hence we can see that application of Einstein's signalling procedure along a closed time-like curve leads to a paradox. The situation is illustrated in figure 5.2.

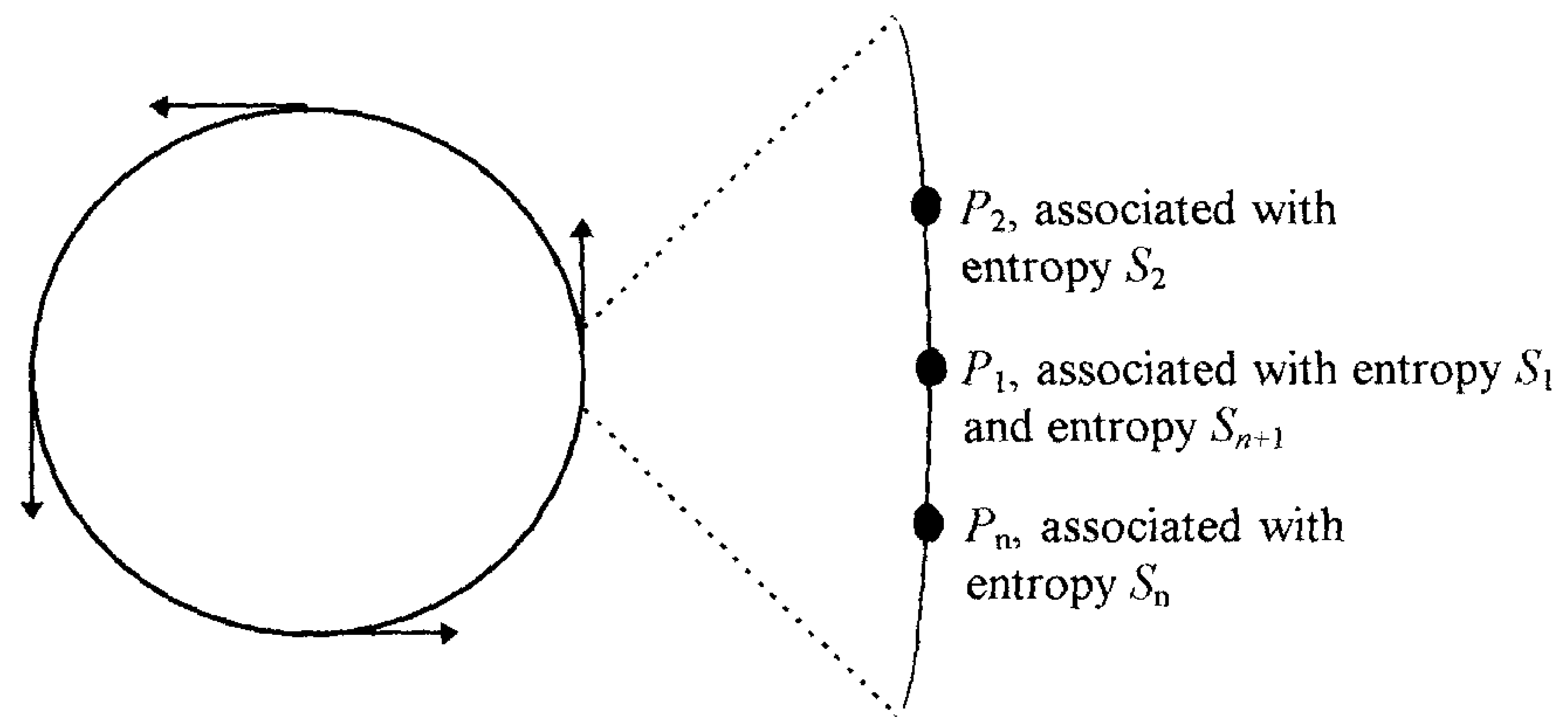


Fig. 5.2 On the left, a closed time-like curve in a Gödelian universe is illustrated. The arrows indicate the temporal orientation of the curve as established at different points by Einstein's signalling method. On the right, a detail of the curve is illustrated. Three arbitrary points, P_n, P_1 and P_2 are illustrated. The entropy associated with each point is indicated. It can be seen that the arbitrary point P_1 is, paradoxically, associated with two different entropies.

Einstein hints at the paradox when he ponders how we might establish the temporal orientation of a time-like curve in a universe modelled on the basis of his field equations, although it is not clear whether he has actually noticed the paradox. He suggests that whilst we might be able to establish a temporal orientation in a local temporal region using the signalling method, this method will inevitably lead to incoherent results when applied globally to time-like curves which are closed.

> "If, therefore, *B* and *A* are two, sufficiently neighboring, world-points, which can be connected by a time-like line, then the assertion: "*B* is before *A*," makes physical sense. But does this assertion still make sense, if the points, which are connected by the time-like line, are arbitrarily far separated from each other? Certainly not, if there exist point-series connectable by time-like lines in such a way that each point precedes temporally the preceding one, *and if the series is closed in itself.*" (Einstein 1949, p.688)

We need to consider, therefore, what the implications are of the paradox, and whether the paradox can be resolved.

3 Two Responses To The Paradox Of Entropy Increase Around Closed Time-Like Curves

One possible response to the paradox of entropy increase along a closed time-like curve is to conclude that universes containing such closed time-like curves, specifically Gödel's rotating universes, are not physically possible, on the grounds that any universe containing a closed time-like curve cannot conform to the second law of thermodynamics. This would be a useful result for a proponent of an objectively distinguished present account of the temporal metaphysics of our universe, since the fact that such an account could not be given of a Gödelian universe would not seem to have any implications for our universe if Gödelian universes are not physically possible.

An alternative response is to argue that for a universe to be physically possible it need not conform to all the laws of physics to which our universe conforms. We could allow that Gödelian universes are physically possible even though they do not conform to the second law of thermodynamics. However, this is problematic if we consider that the second law of thermodynamics plays some role in relation to the temporal metaphysics of our universe.

I shall consider the merits and demerits of these two possible responses in the following two sections.

(a) Denying The Physical Possibility Of Gödelian Universes

How might we motivate the claim that Gödelian universes are not physically possible because they contain closed time-like curves? The universes which Gödel modelled are modelled on the basis of Einstein's field equations and they are thus possible from the point of view of general relativity. However, we may consider that the existence of closed time-like curves in Gödelian universes renders such universes incompatible with the second law of thermodynamics, and that this becomes evident when we attempt to establish the temporal orientation along a closed time-like curve as a whole.

If we assume that a universe is physically possible only if it conforms to *all* physical laws, then we can conclude that the non-conformity of universes containing closed time-like curves to a particular physical law, the second law of thermodynamics, renders such universes physically impossible, even though they are modelled on the basis of another physical law, Einstein's field equations.

Let us consider the two assumptions which have to be made in order to reach the conclusion that universes containing closed time-like curves are physically impossible. Firstly, we need to assume that the existence of closed time-like curves in a universe does actually render that universe incompatible with the second law of thermodynamics. The paradox which arises if we attempt to apply Einstein's signalling technique along an entire closed time-like curve certainly seems to suggest that such curves are incompatible with the second law.

The second assumption which we need to make if we are to conclude that universes containing closed time-like curves are physically impossible is that a universe is physically possible only if it conforms to all physical laws. We need to be clear however about what we mean by "all physical laws". The fact that the universe which we inhabit conforms to a particular set of physical laws does not necessarily indicate that the only universes which are physically possible are those which conform to the same set of physical laws.

Might there not be other possible physical laws than those which obtain in our universe? If so, then a universe which conformed to these other physical laws would be physically possible. It may be that universes are physically possible which only conform to some of the physical laws to which our universe conforms, or it may indeed be that universes are physically possible which do not conform to any of the physical laws to which our universe conforms. Thus to assume that a universe is physically possible only if it conforms to all physical laws, where by "all physical laws" we mean "all the physical laws to which our universe conforms", is to make an assumption which cannot simply be taken for granted. We can see that this line of thought leads to the alternative response to the paradox arising from Einstein's signalling technique.

(b) Arguing For The Physical Possibility Of Universes Which Do Not Conform To All The Physical Laws To Which Our Universe Conforms

Although Gödelian universes do not appear to be compatible with the second law of thermodynamics, is there anything to prevent us assuming that a universe is physically possible even if it does not conform to all the physical laws to which our universe conforms?

Our universe conforms to a particular set of physical laws, which I shall term Set One. We can therefore deduce that universes which conform to Set One are physically possible.[14] Let us suppose, for purposes of illustration, that Set One consists of just two

[14] It may be that only some of the universes which conform to Set One are physically possible, those which also satisfy a certain set of initial conditions. This is a complication which I will set to one side at this stage.

physical laws, L_1 and L_2, in other words that our universe conforms to just two physical laws.

Set One = $\{L_1, L_2\}$

It is possible to envisage at least three other sets as follows.

Set Two = $\{L_1, M_{2)}$
Set Three = $\{M_1, L_2\}$
Set Four = $\{M_1, M_2\}$

All the sets consist of the same number of physical laws as the number of physical laws to which our universe conforms. However, in the cases of Sets Two and Three, one of the physical laws of which the set consists is not a physical law to which our universe conforms. In the case of Set Four neither of the physical laws of which the set consists are physical laws to which our universe conforms.

We can see therefore that there are a variety of different approaches we can take when assessing the physical possibility of a universe. The strictest approach to physical possibility is to require that unless a universe conforms to every physical law to which our universe conforms, Set One in the example above, it is not physically possible. The most lenient approach is to allow that even universes which do not conform to any of the physical laws to which our universe conforms, Set Four in the example above, are physically possible.[15]

In the light of this analysis, we can see that Gödel appears only to require that a universe should conform to one physical law from our universe, Einstein's field equations, for it to be physically possible. If universes containing closed time-like curves are incompatible with the second law of thermodynamics, we might require that a universe should conform to this law as well as to Einstein's field equations for it to be physically possible. Likewise, when we consider other physical laws to which our universe conforms, we will have to consider whether universes containing closed time-like curves are compatible with these laws, and if not, whether we wish the to deny physical possibility to universes containing closed time-like curves on that basis.

An important point to note, however, is that whether we require a logically

[15] Additionally, universes may be physically possible which conform to more or less physical laws than the physical laws to which our universe conforms. I shall set this consideration to one side.

possible universe to conform to all or some or none of the physical laws to which our own universe conforms before we allow that such a universe is physically possible, there does not appear to be any means of testing our requirement. The most coherent claim we can make in this context is that a universe is at least physically possible if it conforms to all the physical laws to which our own universe conforms, given that we know that one universe which conforms to all the physical laws to which our own universe conforms actually exists, namely our own universe. Whether however logically possible universes which do not conform to all the physical laws to which our universe conforms are nonetheless physically possible appears to be undecideable.

4 Is It Always Possible To Give An Objectively Distinguished Present Account Of Universes Which Conform To The Second Law Of Thermodynamics?

Let us consider an arbitrary universe, which I will refer to as U_0, which conforms to the second law of thermodynamics. Is it always the case that it will be possible to give an objectively distinguished present account of U_0?

We have already seen that a universe which contains closed time-like curves cannot conform to the second law of thermodynamics. Therefore, if U_0 conforms to the second law of thermodynamics, it cannot contain problematic space-time structures such as closed time-like curves. Indeed, it cannot by implication contain any space-time structure which is incompatible with the second law of thermodynamics.

In order for U_0 to conform to the cosmological[16] version of the second law of thermodynamics, the following conditions must hold.

(T1) A sequence of global time slices can be identified in U_0 such that the time slice with the lowest entropy and the time slice with the highest entropy are at opposite ends of the sequence.

(T2) For any two adjacent global time slices in U_0, the time slice which is nearer to the time slice with the highest entropy has either the same or a higher entropy than the time slice which is further from the time slice with the highest entropy.

Notice that I am now assigning an entropy to a global time slice as a whole. This would involve adding all the entropies of those systems which are contained in the time slice at the moment of time defined by the time slice. Since the time slice is global, it constitutes an isolated system, and therefore its entropy constitutes the entropy of the universe U_0 at the moment of time defined by the time slice. If (T1) and (T2) hold for U_0, therefore, the second law of thermodynamics holds for U_0. It appears in principle, therefore, that if a structurally simple universe like U_0 is compatible with the second law of thermodynamics, at least the cosmological formulation of that law, it must be possible to define a sequence of global time slices within U_0, as illustrated in figure 5.3.[17]

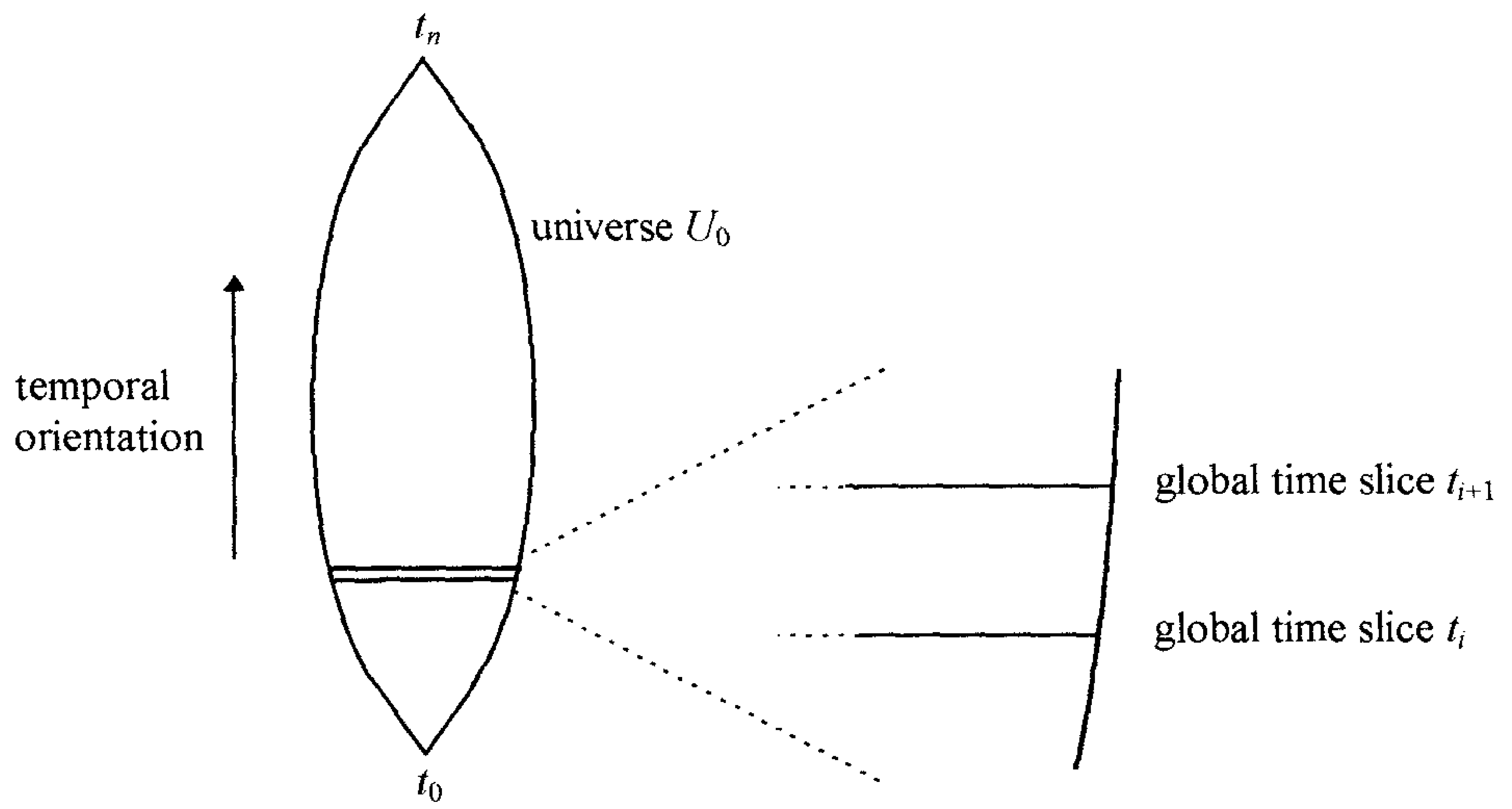


Fig. 5.3 A structurally simple universe U_0, shown on the left, can be foliated into a sequence of global time slices. One arbitrary pair of time slices is shown in detail on the right. If U_0 satisfies conditions (T1) and (T2) (see text), and if t_n has a higher entropy than t_0, then a temporal orientation can be assigned to the universe as indicated by the arrow which points from earlier moments to later moments. The representation of the universe is based on the representation of a universe given by Penrose 1989, p.325 (see footnote 19).

However, the ability to define a sequence of global time slices in a universe is precisely what is required if we wish to be able to give a physically distinguished present account of the temporal metaphysics of that universe. Therefore it appears that

[16] Confer footnote 10.

[17] Assuming that a temporal orientation can be assigned to U_0, it can be represented as having a first moment, t_0, and a last moment, t_n. Following Penrose 1989, I have represented the spatial extension of the universe on the horizontal axis and the temporal duration of the universe on the vertical axis. The universe is thus shown expanding from some initial point t_0 for half of its duration before contracting again to some final point t_n. The diagram is a simplification, since the so-called "big crunch", the final stage of the universe, may be very different from the "big bang", the initial stage of the universe. Indeed, the final stage would appear to be necessarily different to the initial stage if the universe conforms to the second law of thermodynamics, since the final stage has a high entropy whilst the initial stage has a low entropy. The requirement with which we are concerned, however, is that a sequence of global time slices should be definable. I have represented the time slices as lines, but this representation is not intended to preclude the possibility that a time slice, a moment of tme, may have a "thickness" or duration.

any universe which conforms to the second law of thermodynamics is one of which it is possible to give a physically distinguished present account.

6 Conclusion

I have suggested in this chapter that a universe can only conform to the second law of thermodynamics if it is possible to define at least one sequence of global time slices along which entropy increases, where that sequence conforms to conditions (T1) and (T2). This sequence is capable of constituting the privileged sequence of global time slices which a physically distinguished present account requires. Thus a universe which conforms to the second law of thermodynamics is a universe of which a physically distinguished present account could be given.

A presentist can assert that only one global time slice actually exists, all the other time slices in the sequence being merely theoretical constructs. A growing block universe theorist or growing determinacy theorist can assert that although some or all of the time slices in the sequence exist, one of the time slices is objectively distinct from the other time slices.

In the context of demonstrating that a paradox arises when a thermodynamic system is placed on a closed time-like curve, I investigated the second law of thermodynamics. This law can be viewed as a constraint upon the physical possibility of a universe. I considered whether, if a universe did not conform to the second law of thermodynamics, we would be entitled to consider it physically impossible.

This suggests the structure of a more general argument against Gödelian universes, based on the possibility that such universes might not conform to all the physical laws to which our universe conforms. It can be argued, as was examined in the current chapter, that unless a universe conforms to all the physical laws to which our universe conforms, we are not entitled to assume that such a universe is physically possible.

6

Interpretations Of Quantum Mechanics

1 Introduction

I begin this chapter by examining the wave-like and particle-like behaviour of quantum entities. This acts as a prelude to an examination of various interpretations of quantum mechanics. I consider the concept of measurement implied by the different interpretations, before addressing whether performing a measurement upon a quantum system produces an irreversible evolution in the state of that system. I consider an argument due to Penrose (1989) in favour of the conclusion that quantum measurement produces irreversible state evolutions. However, I also consider a demonstration by Aharanov, Bergmann and Lebowitz (ABL) that it is possible to prepare quantum systems in such a way that reversible measurements can be made upon them. ABL suggest that it is the irreversibility of time in the universe as a whole which is reflected in the irreversibility of measurement at the quantum level. The various results obtained in this chapter turn out to have implications for the physical possibility of Gödelian universes, and this is examined in chapter 7.

2 The Wave-Like And Particle-Like Behaviour Of Quantum Entities

One of the factors which led to the formulation of quantum mechanics was the observation that very small material entities, of the order of 10^{-11} m in size, can exhibit two types of behaviour.

On the one hand, very small material entities can behave as if they are point particles, localized in space. On the other hand, they can behave as if they are waves, spread out in space. An experiment exists which lucidly illustrates this dual nature of matter. The experiment in question, known as the two slit experiment, consists of the apparatus illustrated in figure 6.1.

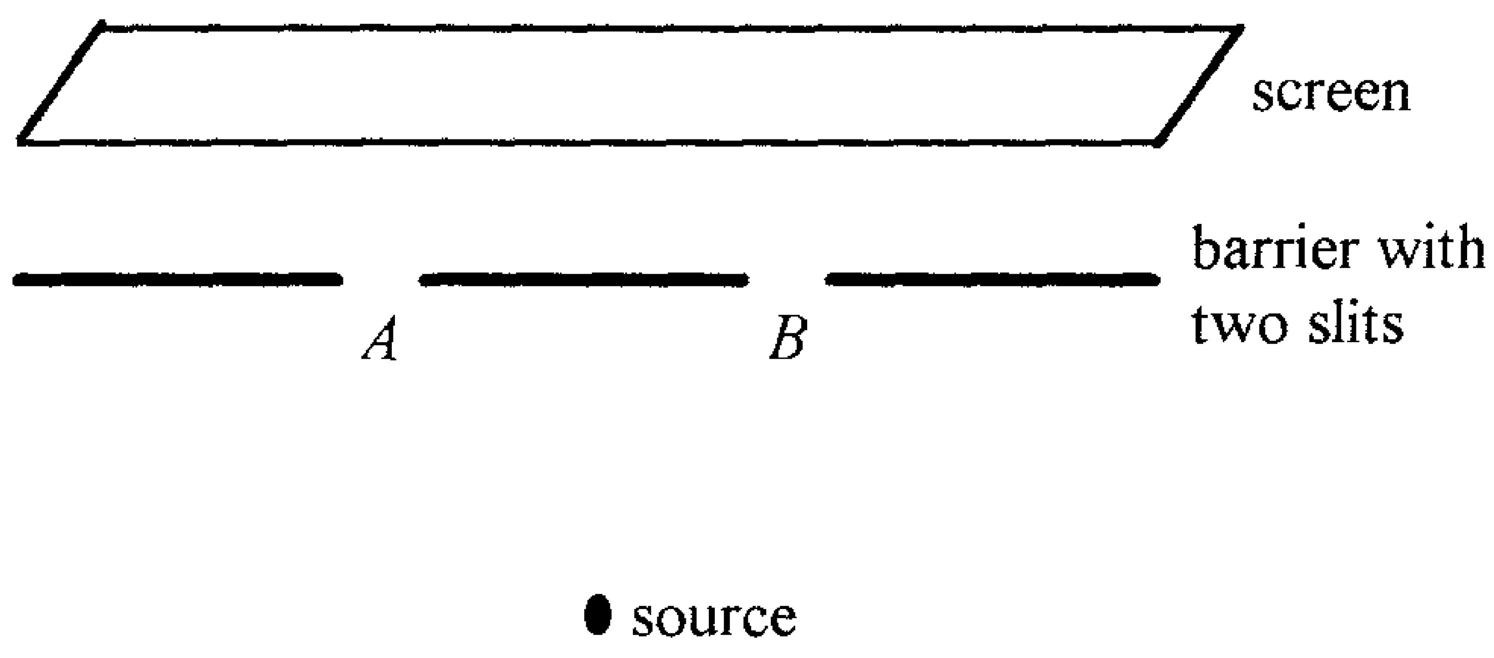
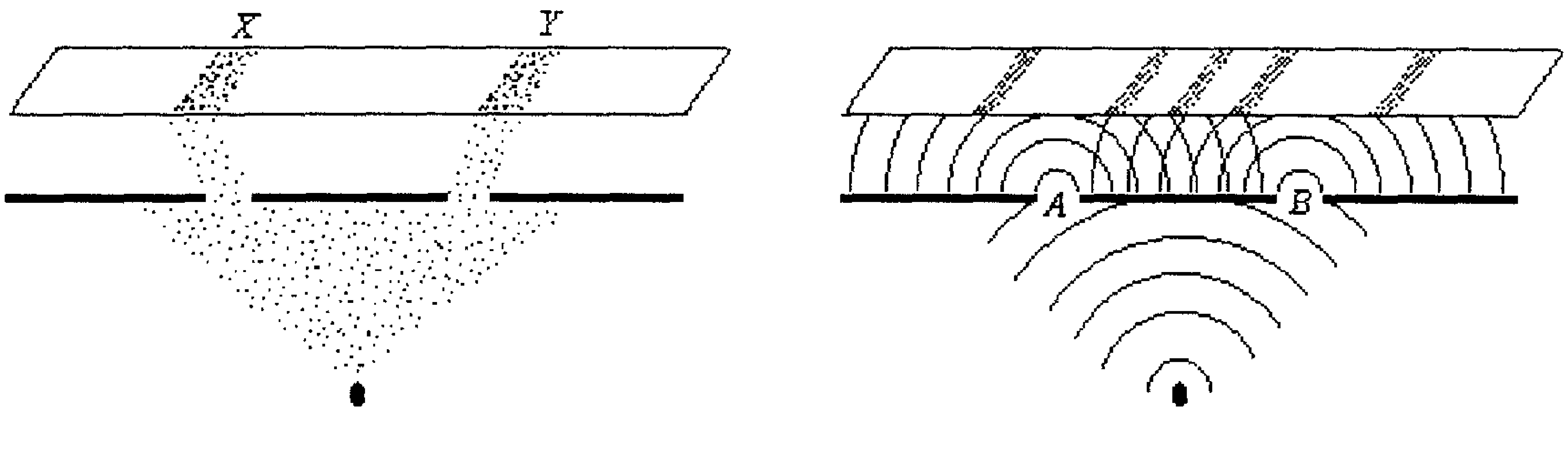


Fig. 6.1 The apparatus for the two slit experiment consists of a source, a barrier with two slits *A* and *B*, and a screen. What is emitted from the source depends upon the particular version of the experiment which is being carried out. The diagram is based on the one given by Coveney and Highfield 1990, p.122.

For the first version of the experiment, suppose that the source emits classical particles[1], that is, particles which are much larger than atoms such as, for example, tennis balls. If the source emits these particles one at a time in the general direction of the barrier, a wall with two slits in it, then these particles either hit the barrier and are deflected, or they pass through slit *A* or through slit *B*. The particles which pass through the barrier accumulate at the screen at point *X* or point *Y*, as illustrated in figure 6.2 (a).

For the second version of the experiment, suppose that the source consists of an oscillating lever which is placed in a water tank along with the barrier and the screen. The source then emits waves, and each wave emitted by the source passes through both slit *A* and slit *B*, so that *A* and *B* act as secondary sources of waves. The waves emitted from *A* and *B* interfere so that where the peak of a wave from *A* meets the trough of a wave from *B*, the waves cancel, and where the peak of a wave from *A* meets the peak of a wave from *B*, or where the trough of a wave from *A* meets the trough of a wave from *B*, the waves re-enforce. If the screen detects the height of a wave, then an interference pattern is produced on it, as illustrated in figure 6.2(b).

[1] In reality, there are no such entities as classical particles, since the description of an entity's behaviour provided by quantum mechanics is theoretically applicable at any scale. At macroscopic scales, however, effects arising from the quantum behaviour of an entity are usually undetectable, so that it is legitimate to treat such entities as classical. That is, their behaviour is describable in terms of classical Newtonian laws of physics.



(a) (b)

Fig. 6.2 (a) The two slit experiment conducted with a source emitting classical particles. Particles accumulate at points X or Y on the screen. (b) The two slit experiment conducted with a source emitting waves, or quantum entities exhibiting both wave-like and particle-like behaviour. An interference pattern builds up on the screen. Dark regions correspond to high wave intensity, light regions to low wave intensity. Slits A and B act as secondary wave sources. The diagram is based on the one given by Coveney and Highfield 1990, p.122.

For the third version of the experiment, suppose that the source emits quantum entities, that is, entities which are the size of atoms or smaller such as, for example, electrons or photons. The screen used in this version of the experiment detects the arrival of a quantum entity by, for example, changing from a light colour to a dark colour.[2] If we design the source so that it only emits one entity at a time, we might expect the pattern illustrated in figure 6.2 (a) to gradually build up over time on the screen as the number of entities emitted increases. What we find, however, is that the pattern illustrated in figure 6.2 (b) builds up over time. This indicates that, although the source is only emitting one quantum entity at a time, the wave-like aspect of the entity leads to an interference effect. The entity behaves like a wave after it is emitted, passing through both slits in the barrier, the two resultant waves interfering. However, if we were to observe the screen, we would find that the entity is only detected at one point on the screen when the entity arrives there. The screen, which in effect measures the position of the entity, causes the entity to cease to behave like a wave and instead to behave like a particle.

If we consider the first version of the two slit experiment, it is evident that if we have a complete description of the velocity of a classical particle, that is, its speed and the direction in which it is travelling, then we can predict whether it will hit the barrier or pass through one of the slits to hit the screen. We can also predict which, if either, of the slits it will pass through, and therefore which, if either, of the points X and Y on the screen it will hit.

[2] Where the quantum entities being emitted are photons, for example, an undeveloped photographic film can be used which permanently changes colour at the point where it is exposed to a photon.

In the third version of the two slit experiment, however, the quantum mechanical description of the quantum entity just after it is emitted by the source does not predict either through which slit the entity will pass[3], or at which point on the screen the entity will be detected. The quantum mechanical description merely assigns a probability that the entity will be detected in a particular spatial interval on the screen. There is thus a high probability that the entity will be detected in one of the intervals where the waves from *A* and *B* re-enforce at the screen, and a low probability that the entity will be detected in one of the intervals where the waves from *A* and *B* cancel at the screen.

In general, the quantum mechanical description of the position of a quantum entity indicates the probability of finding that entity in a particular interval of space. Similarly, the quantum mechanical description of the momentum of a quantum entity indicates the probability of finding that entity with a particular momentum.[4] Therefore, in the two slit experiment, we can be sure that if a thousand quantum entities are emitted one by one, an interference pattern will build up on the screen composed of a thousand entity detections by the screen. However, for any particular quantum entity, we can only give a probability of where it will be detected on the screen.

The quantum mechanical description of a quantum entity such as a photon emitted by the source in the two slit experiment is given in terms of the wave function of that entity.[5] The behaviour of a quantum entity as described by the wave function of that entity is reversible in time.[6] Suppose that the wave function implies that the probability of finding a particular quantum entity in the spatial interval P is 0.1 at moment t_i and 0.2 at moment t_j.[7] From the point of view of the wave function description, t_i could be either before or after t_j. If we think of the wave function as implying the set of possible trajectories of a quantum entity over a period of time, then the temporal reversibility of the wave function implies that a quantum entity could

[3] Indeed, if we attempt to detect through which slit the entity passes, which amounts to measuring its position at the barrier, the entity ceases to behave like a wave, and behaves instead like a particle. In this case a classical pattern like that illustrated in figure 6.2 (a) builds up on the screen.

[4] The momentum of a particle is its mass multiplied by its velocity. Position and momentum in quantum mechanics are related by Heisenberg's uncertainty principle, which indicates that the more precisely we measure the position of a quantum entity, the less precisely we can measure its momentum, and vice versa. A similar relationship pertains between energy and time. The more precisely we measure the energy which a quantum entity has, the less precisely we can determine the particular moment of time at which the entity has that energy.

[5] An account of the mathematical representation of wave functions, and the methods of obtaining information from them by performing mathematical operations upon them, can be found in Beiser 1987, chapter 5. See also Hughes 1989, chapter 2.

[6] To be precise, the Schrödinger equation which represents the wave function of a quantum entity is invariant under Wigner transformations, but is not invariant under $t \rightarrow -t$.

travel in either direction along a particular trajectory over a period of time.

In the two slit experiment, the wave function describes, in probabilistic terms, the behaviour of a quantum entity from the moment it is emitted from the source to the moment it is detected at the screen. However, once the entity is detected at the screen, the wave function which described its behaviour until the moment of detection no longer provides a valid description. This is evident if we consider what the wave function implies about the position of the entity. On the basis of the wave function, we can only calculate a probability between 1 and 0 that the entity is located in a particular interval on the screen. So, for example, the wave function might imply that there is a probability of 0.2 that the entity is located in some interval P on the screen. However, since the screen detects the entity, we can say precisely where the entity is when it hits the screen. If the entity is in fact detected in the interval P, we can say there is a probability of 1 that the entity is located in the interval P.

The detection of the location of a quantum entity by the screen in the two slit experiment implies that the wave function which described the behaviour of the entity previously is no longer suitable as a description of the behaviour of that entity. Detection of the position of a quantum entity, which constitutes a position measurement, produces an irreversible change in the behaviour of that entity, which is popularly termed the "collapse of the wave function".[8] After detection, the behaviour of the quantum entity has to be given in terms of a new wave function, and the behaviour of the quantum entity before it was detected cannot be retrodicted from this new wave function. Measurement therefore appears to introduce irreversibility into the description of the behaviour of a quantum entity.[9] In section 4 of the current chapter I will consider evidence for and against the claim that measurement does indeed introduce irreversibility in the way that it appears to do. I will examine an argument from Penrose[10] which supports the claim that measurement introduces irreversibility into the

[7] Note that a wave function only tells us the probability of finding a quantum entity in a particular spatial interval. The wave function actually gives a probability of zero of finding a quantum entity at a specific point in space.

[8] The expression "collapse of the wave function" is potentially misleading, suggesting as it does that some kind of physical collapse occurs at the moment that a measurement is made upon a quantum system. The mathematical representation of quantum mechanics reveals only that a measurement provides us with a determinate value for some physical variable such as position. The mathematical representation does not express how this value derives from the state of the quantum system just prior to the measurement.

[9] It is interesting to note in this context that Einstein comments, in his short reply to Gödel, that "*according to our present knowledge*, all elementary processes are reversible" (Einstein 1949, p.688, italics in original). He is contrasting elementary processes with the growth of entropy, which the second law of thermodynamics implies is irreversible. Whilst it is not entirely clear what would count as an elementary process for Einstein in this context, he is apparently ignoring the fact that measurement appears to introduce irreversibility into a system's evolution through time.

[10] Confer Penrose 1989.

description of the behaviour of quantum entities, and an argument from Aharanov, Bergmann and Lebowitz[11] which may cast some doubt on this claim.

Given that the wave function of a quantum entity only tells us the probability of finding that entity at a particular spatial location at a particular moment in time, it might appear tempting to interpret the wave function as a description of how much we know about the entity. This interpretation would imply that the entity is really at a definite location, even when a measurement is not being performed upon it, but that we can only assign a probability to where it is likely to be when we are not performing a measurement. The physicist David Bohm interpreted quantum mechanics in this way.

On the other hand, the fact that a single quantum entity in the two slit experiment lands at a point on the screen which constitutes part of an interference pattern, rather than part of a classical distribution, may indicate that whilst the quantum entity is passing through the two slits, it is not localized in space, but is rather behaving like a wave which passes through both of the slits. It is therefore possible to interpret the wave function as representing not the state of our knowledge, but the wave-like nature of the quantum entity when it is not being measured.

Just as there is more than one way to interpret the wave function of a quantum entity, so there is more than one way to interpret the theory of quantum mechanics as a whole. Indeed, the interpretation placed upon the wave function often forms the basis for the overall interpretation of quantum mechanics. In the next section, therefore, I am going to consider a variety of interpretations of quantum mechanics which have been proposed since the theory was first formulated. As will become apparent, the implications of quantum mechanics for temporal metaphysics depend to some extent on the interpretation placed upon quantum mechanics.

3 Theories Of Quantum Mechanics

Whilst I have yet to examine whether performing a measurement on a quantum system[12] brings about an irreversible change in the evolution of that system, a useful preliminary to such an examination is an assessment of what constitutes a measurement and what constitutes a quantum system. There are a number of different theories of quantum mechanics, and the various theories imply different concepts of *measurement* and different concepts of *quantum system*. There is no general agreement as to which, if any, of these theories is correct.

[11] Confer Aharanov, Bergmann and Lebowitz 1964.

[12] I will sometimes refer to "a measurement on a quantum system" as a *quantum measurement*.

I am therefore going to consider the various theories of quantum mechanics which are available, and the concepts of *measurement* and *quantum system* implied by them, before attempting to assess what implications the various theories have for the debate between the advocates of static block universe accounts and objectively distinguished present accounts of temporal metaphysics.

(a) The Copenhagen Interpretation

Niels Bohr[13], whose theoretical work contributed significantly towards the development of quantum mechanics, adopted an approach towards the interpretation of a measurement on a quantum system which has remained popular, particularly amongst those physicists who do not consider investigating the philosophical implications of quantum mechanics to be part of their role. Bohr's approach, which is usually referred to as the Copenhagen[14] interpretation, is based upon the premise that our natural languages[15] can only satisfactorily describe the contents of our experience. We experience the physical world as "classical", as composed of physical objects which are much larger than atoms and which broadly obey Newtonian mechanics. Our natural languages therefore have developed in order to describe the behaviour of such objects. Quantum mechanics however applies to entities which are much smaller than any objects of which we can have a direct experience. Therefore, any attempt to explain in a natural language what the mathematical procedures of quantum mechanics represent must inevitably fail.

In order to perform a measurement, we employ large objects such as lamps, screens and photo-cells which our natural languages are well-suited to describing. However, when we are making a measurement upon a quantum entity, our languages are not equipped to describe the behaviour of the entity itself.

This line of thought led Bohr and other physicists who played an important part in formulating quantum mechanics such as Max Born[16] and Werner Heisenberg[17] to conclude that we are incapable of translating the mathematical procedures of quantum mechanics into a natural language description of what is happening at the quantum

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[13] Confer Bohr 1935, 1935a.

[14] Copenhagen was the city where Bohr lived and worked.

[15] A natural language is a language which has developed amongst a language community over many generations in a largely uncoordinated fashion to serve many different purposes. It can be distinguished from a formal language devised to serve a specific purpose.

[16] Confer Born 1926.

[17] Confer Heisenberg 1927.

level.[18] We have to be content with the fact that the mathematical procedures appear to give us the correct results at the macroscopic level.

This approach, which is essentially instrumentalist (a description more appropriately applied to Heisenberg than to Bohr, in fact) implies that the mathematical procedures of quantum mechanics are useful tools, but tools whose intrinsic meaning cannot be understood. Indeed, Bohr and some of his successors make the stronger claim, which is reminiscent of logical positivism in its import, that it is not simply that we cannot describe what is happening at the quantum level, but that there is nothing to be described. Bohr expresses this thought as follows.

> "There is no quantum world. There is only an abstract quantum description." (Bohr, quoted by Herbert 1985, p.17)

For Bohr, quantum entities are only real when they are measured. This is in fact a metaphysical claim, since there is no more evidence that quantum entities are not real when they are not being measured than that they are real. What we might term the strong version of the Copenhagen interpretation is therefore as problematic as any theory which asserts the reality of quantum entities when they are not being measured.

The weak version of the Copenhagen interpretation, the version which asserts that we are not entitled to deduce anything about the nature of reality at the quantum level from the mathematical procedures of quantum mechanics, limits us to describing the mechanics and results of measurement without any possibility of understanding what is happening at the level of quantum entities. As such, it implies that we adopt Wittgenstein's advice, in this case in relation to quantum entities.

> "Whereof one cannot speak, thereof one must be silent." (Wittgenstein 1922, p.189)

This approach, whilst coherent, is philosophically dissatisfying and has not prevented numerous other interpretations being offered as to what happens when a measurement is made upon a quantum system.

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[18] The term "quantum level" is used here to denote scales of the order of 10^{-11} m and smaller, the atomic scale. As pointed out previously, however, the distinction between the quantum and classical levels is an artificial one since quantum mechanics applies at all scales, though its effects are only evident on the atomic scale. Confer footnote 1.

(b) The Conscious Observer Account

In order to demonstrate the implications of the wave function account of the evolution of a quantum system which he had formulated, Erwin Schrödinger devised a thought experiment which has come to be known as *Schrödinger's cat*. Schrödinger describes the experiment as follows.

> "A cat is penned up in a steel chamber, along with the following diabolical device (which must be secured against direct interference by the cat): in a Geiger counter there is a tiny bit of radioactive substance, *so* small, that *perhaps* in the course of one hour one of the atoms decays, but also, with equal probability, perhaps none; if it happens, the counter tube discharges and through a relay releases a hammer which shatters a small flask of hydrocyanic acid. If one has left this entire system to itself for an hour, one would say that the cat still lives *if* meanwhile no atom has decayed. The first atomic decay would have poisoned it. The ψ-function of the entire system would express this by having in it the living and the dead cat (pardon the expression) mixed or smeared out in equal parts." (Schrödinger 1935, p.157)

This thought experiment has the effect of magnifying up to the macroscopic level the indeterminacy which is implied by the wave function description of a system at the quantum level. The wave function of the sample of radioactive substance evolves into a superposition of states, one part of the wave function relating to the situation in which an atom in the sample has not decayed, the other part of the wave function relating to the situation in which an atom in the sample has decayed. As the experiment is devised, each part of the wave function has an amplitude of $1/\sqrt{2}$, indicating that there is a probability of one half that an atom in the sample will be found to have decayed when the chamber is opened at the end of an hour. However, if an atom does decay, this will have the effect of releasing the poison into the chamber and killing the cat. Therefore, there is also a probability of one half that the cat will be found dead when the chamber is opened at the end of an hour.

As the experiment is presented, it is the opening of the chamber at the end of an hour which constitutes a measurement upon the quantum system. Therefore, until the measurement is made, the entire system inside the chamber, including the cat, is in a superposition of states. The notion of a macroscopic object such as a cat evolving into a superposition of states, one state in which the cat is alive and another state in which the cat is dead, is one which clearly does not conform with our experience of the physical world. Schrödinger's thought experiment, therefore, serves to illustrate just how unlike the physical world as we experience it is the physical world implied by the wave function representation, if, contrary to the Copenhagen interpretation, we allow that the wave function representation has any implications at all.

One use of Schrödinger's thought experiment, aside from providing a graphic illustration of the nature of the physical world when that world is described in quantum mechanical terms, is to provide a context in which answers to the question of what constitutes a measurement upon a quantum system can be formulated. If, for example, we accept that the system in the chamber in Schrödinger's thought experiment evolves into a superposition of states[19] and remains in a superposition until someone opens the chamber, then this raises the question of what distinguishes the chamber when it is closed from the chamber when it is opened. The answer seems to be that when the chamber is opened the system within it is observed.

Various theorists, including John von Neumann and Eugene Wigner, both of whom contributed to the formulation and development of quantum mechanics[20], broadly accepted the description of Schrödinger's thought experiment as it stands. According to the account which such theorists propose, the quantum system inside the chamber, which includes the cat, does indeed evolve into a superposition. Furthermore, the system only "collapses" from a superposition into a determinate state when an observer opens the chamber. The assertion in this account which distinguishes it from other accounts which we will consider is that it is the fact that the observer is conscious which leads to the instantaneous transition of the quantum system from an indeterminate superposition into a determinate state. I shall therefore term this the conscious observer account. In general, the conscious observer account states that a quantum system which evolves into a superposition remains in a superposition until a conscious observer intervenes in the system. This claim has two significant implications.

Schrödinger's thought experiment implies that if a macroscopic physical object such as a Geiger counter interacts with a quantum entity in a superposition, then the macroscopic physical object enters into a superposition along with the quantum entity, provided that no conscious observer is observing the macroscopic object. If, therefore, a piece of measuring apparatus is used to detect whether a radioactive sample has decayed

[19] Strictly, it is the wave function representing the system which evolves into a superposition of states. For convenience, however, I shall sometimes speak about a system evolving into a superposition, rather than the wave function which represents the system.

or not, the wave function of the system consisting of the measuring apparatus plus the radioactive sample evolves into a superposition. One part of the wave function relates to the apparatus having recorded a decay and the other part of the wave function relates to the apparatus having recorded no decay. The wave function describing the apparatus and sample remains in a superposition for as long as no conscious observer observes the measuring apparatus.

Suppose that someone looks at the measuring apparatus. Given that a human eye is a macroscopic physical object like a piece of measuring apparatus, it would be consistent to expect that the wave function describing the eye, apparatus and sample would evolve into a superposition. Similarly, since the human brain is a macroscopic physical object, it would be consistent to expect that the wave function describing the brain, eye, apparatus and sample would evolve into a superposition.

According to the conscious observer account, however, when the observer observing a quantum system is conscious, the consciousness of the observer causes the transition of the wave function of the system out of a superposition and into a determinate state. The conscious observer account therefore implies that consciousness is distinct from the physical brain, since consciousness does not enter into a superposition along with the physical brain, but rather collapses any superposition into a determinate state.[21]

A second implication is evident when we consider Schrödinger's original thought experiment. If we accept that the wave function describing the system inside the chamber, including the cat, is in a superposition until a conscious observer opens the chamber, this implies that the cat does not count as a conscious observer, and therefore effectively restricts consciousness, at least of the kind required to collapse wave functions, to human beings. On some versions of the conscious observer account, however, the cat never enters into a superposition because the cat is considered to possess a sufficient level of consciousness to collapse the wave function. This then raises the question of what level of consciousness is required to cause wave function collapse. Would an amoeba, for example, possess sufficient consciousness to collapse a wave function?

[20] Confer von Neumann 1932, Wigner 1961, 1963. Von Neumann 1932 was completed before Schrödinger formulated his thought experiment.

[21] It could be argued that it is the physical structure of the brain which collapses a wave function out of a superposition, so that a brain never in fact enters into a superposition. In this case, it would not be necessary to conceive of consciousness as something distinct from the physical brain. However, an account would still be required of what it is about the physical structure of the brain which enables the brain to collapse a wave function out of a superposition. Confer Penrose 1989, chapter 9.

The conscious observer account is problematic because it is couched in terms of consciousness, a concept which is problematic in itself. The account implies that consciousness is not physical and, partly as a consequence of the implied non-physicality of consciousness, the actual mechanism by which consciousness causes a wave function in a superposition to collapse into a determinate state remains mysterious. Nonetheless, the account does at least provide us with a precise definition of what constitutes a measurement upon a quantum system, and it implies a definition of what constitutes a quantum system. A measurement occurs when a conscious observer observes a quantum system. A quantum system is a system which can be described by a wave function and which therefore can evolve into a superposition of states.

Dissatisfaction with the conscious observer account has suggested two opposing strategies to theorists. On the one hand, some theorists have attempted to extend classical determinacy down to the quantum level. This approach is employed in hidden variable accounts of measurement and also in a theory developed by David Bohm.[22] On the other hand, some theorists have proposed that quantum indeterminacy extends all the way up to the level of the observer and beyond. This is the approach adopted by advocates of the many worlds and many minds theories. I will consider these two types of approach over the next four sections.

(c) Hidden Variable Theories

Schrödinger's wave function representation of quantum entities implies that such entities are fundamentally indeterminate when no measurement is being performed upon them, apparently capable of existing in more than one state at the same time.[23] Some theorists, confronted with the kind of implications of the wave function representation which are made evident by Schrödinger's cat, have argued that the indeterminacy implied by the representation indicates that the representation cannot be complete. One response has been to propose that there are various properties of a quantum system which are not measurable, the so-called hidden variables of the quantum system, and that it is these variables which determine the outcome of a

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[22] It can be argued that Bohm's theory is itself a hidden variable account. I have refrained from describing Bohm's theory as a hidden variable account, however, since Basil Hiley, a long standing collaborator with Bohm, and my tutor whilst I was studying physics at B.Sc. level, informed me that Bohm himself used to insist that his theory was not a hidden variable account, on the grounds that none of the variables in his theory were, in fact, hidden.

particular measurement upon such a system.[24]

If hidden variables exist, it may be that advances in experimental technique will eventually allow us to measure them, or it may be that they are by their very nature inaccessible to measurement. The advantage of postulating such variables however is that they permit us to interpret a quantum system as determinate even when no measurement is being performed upon the system. The hidden variable approach implies that the wave function description of a quantum system is only a partial representation of such a system, and that the apparent indeterminacy of an unmeasured quantum system is a consequence of the failure to represent the hidden variables in the wave function.

A simple analogy can be used to illustrate the concept underlying the hidden variable approach. Suppose that a six-sided die is thrown one hundred times. It is found that the die lands forty-six times displaying a one on its uppermost face, and fifty-four times displaying a six on its uppermost face. We can describe the behaviour of this die by stating that the probability of the die displaying a one or a six is approximately a half in each case. Our description contains no explanation of why the die lands as it does, however.

We now cut the die in half and discover that there is a hollow tube between the face with a one on it and the face with a six on it. A lead weight is located in the tube and can move freely along it. The tube is designed in such a way that the face of the die which is uppermost when the die lands is determined by the way in which the die is thrown.

The hidden variable approach to quantum mechanics suggests that describing a quantum system in terms of a wave function is akin to describing the die in the example above in terms of the probability of the die landing with a particular face up. The description of the behaviour of the die in probabilistic terms suggests that whether the die lands on any particular occasion with a six or a one showing is not determined. However, there are factors in this situation, the hollow tube and the disposition of the lead weight within it, which, if they were included in the description of the die, would allow us to give a completely deterministic account of the behaviour of the die. The suggestion made by those who favour the hidden variable approach is that there are

[23] Heisenberg's matrix representation of quantum entities similarly implies the indeterminacy of such entities. Therefore, the hidden variable theories are as much a response to Heisenberg's representation as they are to Schrödinger's representation.

[24] Confer Bell 1966.

factors in a quantum system which are hidden, and that these factors are not represented by the wave function description of such a system. Were these factors evident, however, it would be clear that the behaviour of a quantum system is in fact deterministic.

Whilst it is evident that this approach will appeal to any theorist who is uncomfortable with the claim that quantum systems are indeterminate, it can be demonstrated mathematically that the statistical results predicted by the mathematical representation of quantum systems, as that representation is formulated in standard quantum mechanics, place certain constraints upon the properties of any hidden variable theories which can be postulated for such systems. In order for a hidden variable theory to predict a set of results which match the statistical predictions of standard quantum theory, that is, quantum theory which does not employ hidden variables, a hidden variable theory must conform to these mathematical constraints.[25]

In particular, it appears that if we wish to make determinate predictions using a hidden variable theory in such a way that a sufficiently large number of such predictions reproduce the statistical patterns predicted by standard quantum mechanics, then our hidden variable theory will need to be both contextual and non-local.

A contextual hidden variable theory is one in which a Hermitian operator, the mathematical object which represents a physical quantity in quantum mechanics, can represent different physical quantities if that operator belongs to more than one set of mutually compatible operators. Which physical quantity the operator is taken to represent would depend upon the context of the set of operators in which we are considering the operator.

A non-local hidden variable theory is one in which the hidden variables describing quantum systems which are spatially separated are *not* independent of one another.

The import of these two constraints upon hidden variable theories may not be immediately obvious, but it will suffice to note that the constraints exist.

The main point to note in the present context is that hidden variable theories, if they can be constructed at all, may imply that quantum systems have features which are as problematic as the indeterminacy which the hidden variable theories are designed to alleviate.

If a hidden variable version of quantum mechanics could be formulated, the implication would be that a quantum entity has a determinate existence even when it is not being measured. Therefore the perceived role of measurement in relation to a

[25] Confer Hughes 1989, chapter 6, especially section 8.

quantum entity would change. In standard quantum mechanics, as we have seen, measurement appears to cause the transition of a quantum entity from an indeterminate superposition into a determinate state. If, however, a quantum entity is in a determinate state even before it is measured, then the measurement is simply establishing what that determinate state is, rather than actually bringing it about. Under the auspices of hidden variable theories, therefore, a measurement is just that, an intervention in a system which establishes the state of that system, but which does not bring about a fundamental transition in the state of determinacy of that system. A quantum system, in this context, is any system of which a hidden variable account is required.

If a quantum entity is determinate at all times, as a hidden variable theory would imply, this raises the possibility that its trajectory through space-time is time-reversal invariant. Since full knowledge of the hidden variables in a system would permit us to predict with certainty the outcome of a measurement on that system, Penrose's probabilistic demonstration of irreversibility which I will consider in section 4(a) of the current chapter would no longer be relevant. This would not necessarily prove that the processes describable in terms of a hidden variable theory were reversible, however.

It should be noted that not all hidden variable theories imply that we can describe and predict the behaviour of quantum entities with absolute certainty. Stochastic hidden variable theories only provide us with the probability that a quantum entity will have a particular value for a particular observable. The implication is that the values of the observables of quantum entities develop stochastically over time. Redhead describes stochastic hidden variable theories in the context of the Bell inequality[26] as follows.

> "The idea of [stochastic hidden-variable] theories is that the 'complete' hidden-variable description of the source does not determine the values of local observables possessed by the two particles in the Bell type of experiment, but only the probabilities for possible values to occur. We can think picturesquely that the values of the spin-components in any given direction are developing in time stochastically, the state of the source controlling only the probabilities that

[26] The Bell inequality is an inequality between measurable correlation coefficients in a version of the EPR experiment in which spin-components of quantum entities are measured. The inequality arises as a consequence of assuming that a hidden variable account of quantum mechanics is compatible with a particular concept of "locality", to the effect that "A sharp value for an observable cannot be changed into another sharp value by altering the setting of a remote piece of apparatus." (Redhead 1989, p.82). Confer Bell 1964, Redhead 1989.

particular values will be revealed when subsequent measurements are performed." (Redhead 1989, pp.98-9)

Whilst it appears that a hidden variable theory is possible in principle, it is important to note that no such theory has as yet been successfully formulated. We have however observed some possible implications of the successful formulation of such a theory.

(d) Bohm's Theory

Closely related to hidden variable theories in intent, although not in methodology, is a theory proposed by David Bohm in 1952.[27] Bohm's theory implies that quantum entities are determinate even when they are not being measured, the same implication that a consistent hidden variable theory would have.

According to Bohm, quantum entities such as electrons and photons are particles, and as such they always have a determinate position in space at a particular moment in time. What is required of Bohm's theory, therefore, is an explanation of the type of behaviour which occurs in experiments such as the two slit experiment considered in section 2 of the current chapter and the half-silvered mirror experiment which I will consider in section 4 of the current chapter, behaviour which suggests that quantum entities are behaving as if they were waves rather than particles.

Whilst maintaining that a quantum entity such as an electron or a photon is a particle, Bohm argues that there is another type of quantum entity, the wave function itself. According to Bohm, the wave function of a quantum entity is also a quantum entity, a component of the physical world just as an electron or a photon is a component of the physical world, but a different kind of quantum entity to the particulate quantum entities. Wave functions are spread out through space, and their evolution through time is described by exactly the same mathematical equations as those which describe the evolution through time of Schrödinger's wave functions. The only difference between Bohm's wave functions and Schrödinger's wave functions is one of interpretation. Whilst Schrödinger conceives of a wave function as representing a possible state of a quantum entity, when that entity is behaving like a wave rather than like a particle, Bohm conceives of a wave function as an entity in its own right, distinct from though

[27] The approach to quantum mechanics adopted by Bohm was first hinted at by Louis de Broglie in 1930. A refined version of Bohm's theory was proposed by John Bell in 1982. Confer De Broglie 1930, Bohm 1951, Bohm 1952, Bell 1987.

associated with a particulate quantum entity.

According to Bohm, a wave function has the effect of directing the trajectory of a quantum particle through space, in such a way that the measured behaviour of the particle gives rise to the results predicted by standard quantum theory. We can note therefore that Bohm is not taking issue with the results predicted by standard quantum theory. One way of testing a theory is to compare the results which it predicts with the results obtained experimentally, and experimental results have consistently been in accord with the results predicted by standard quantum theory. What Bohm is rejecting is the interpretation of standard quantum theory which implies that quantum entities can exist in indeterminate states when no measurement is being performed upon them. The postulation of wave functions as actual physical existents alongside particulate quantum entities allows Bohm to reproduce the same predictions as standard quantum mechanics, but without thereby implying that particulate quantum entities can exist in indeterminate states.

Since a particulate quantum entity remains a particle throughout its existence, there is no question of either it or the wave function which guides it "collapsing" when a measurement is made upon the particle. As in the hidden variable theories, a measurement according to Bohm's theory simply serves to establish where exactly a particle is at a particular moment of time. A measurement therefore does not bring about a transition from an indeterminate to a determinate state. Bohm's theory implies that even when we have discovered the location of a particle, the wave function which was guiding that particle remains. Bohm's theory also implies that we cannot perform measurements directly upon wave functions, but can only infer their existence and their behaviour by measuring the behaviour of the particles which they are guiding. A quantum system, in Bohm's account, is therefore any system of which a description in terms of wave functions can be given.

Given that Bohm's theory implies that the state of quantum entities, both particles and wave functions, is always determinate, and given that it implies therefore that measurement does not induce a transition from indeterminacy to determinacy, we will see that as with hidden variable theories, Penrose's argument for the irreversibility of measurement of a quantum system, which I will consider in section 4(a) of the current chapter, is not applicable where that quantum system is conceived of from a Bohmian point of view. We can also note that as with hidden variable theories, this does not necessarily imply that processes which are describable in Bohmian terms are reversible.

Although Bohm's theory allows us to re-establish determinacy at the quantum level, the fact that it predicts, and is indeed designed to predict, exactly the same experimental results as the results predicted by quantum mechanics indicates that there is no way of distinguishing Bohm's theory from standard quantum mechanics in experimental terms. Unless we are able to find some testable implications of Bohm's theory which are different from the testable implications of standard quantum mechanics, the choice between the theories will have to be made on metaphysical grounds. The essence of the metaphysical debate is whether indeterminate quantum states on the one hand or wave functions existing in space on the other hand are felt to be more coherent as components of an interpretation of the physical world.

(e) The Many Worlds Theory

As we have seen, both hidden variable theories and Bohm's theory seek to re-establish the determinacy at the quantum level which is absent from standard quantum mechanics. An alternative reaction to the indeterminacy implied by standard quantum theory is to embrace that indeterminacy, and to incorporate it as an integral component of one's metaphysics. This is the approach adopted by those who favour many worlds and many minds theories of quantum mechanics.

The many worlds interpretation of quantum mechanics was first proposed by Hugh Everett III in 1957.[28] The interpretation arose out of his doctoral work which was supervised by the physicist John Wheeler.[29] The import of the interpretation can be illustrated by reference to the thought experiment in which Schrödinger's cat plays its part. According to Schrödinger's original presentation of the thought experiment, the superposition into which the quantum system inside the closed chamber has evolved collapses into a determinate state when the chamber is opened.

Let us suppose that someone called Hugh has carried out Schrödinger's thought experiment, and that when Hugh opens the chamber, he finds that the cat is dead. Let us suppose, however, that the superposition into which the quantum system inside the closed chamber has evolved has not collapsed, even though the chamber has been opened. Can we reconcile Hugh's observation that the cat is dead with the supposition that the quantum system is still in a superposition?

Everett proposes the following. Suppose that when Hugh opens the chamber,

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[28] Confer Everett 1957.
[29] Confer Wheeler 1981.

rather than the quantum system collapsing into a determinate state, Hugh himself enters into a superposition along with the quantum system he is observing. On this account, Hugh's consciousness does not collapse the superposition, as it does in the conscious observer account. Nonetheless, he only experiences a determinate state. This implies that he only experiences one branch or the other of the superposition, the branch in which the cat is alive or the branch in which the cat is dead.

There are various ways of expressing what happens when Hugh opens the chamber. Everett can be interpreted as saying that when we make a measurement upon a quantum system which is in a superposition, the universe splits. If the quantum system is in a superposition with two branches, then the universe splits into two. Therefore, if the system in the chamber is in a superposition, in one branch of which the cat is dead and in the other branch of which the cat is alive, then when Hugh opens the chamber the universe splits into two universes. Since Hugh is part of the universe, Hugh splits when the universe splits. In one universe, there is a person called Hugh who sees a dead cat in the chamber, in the other universe, there is a person called Hugh who is greeted by a living cat. The problem with this way of expressing what happens when Hugh opens the chamber is that it appears to equate making a measurement with observation by a conscious observer, as in the conscious observer account. The implication of the account just given is that the universe only splits when a conscious observer observes a quantum system. Since however consciousness plays no integral part in the account, that is, it no longer performs the role of collapsing the superposition, it is not clear why the universe should be deemed to split only when a conscious observer makes an observation.

A more consistent way of expressing what happens when Hugh opens the chamber is as follows. At the moment that an atom in the radioactive sample in Schrödinger's thought experiment enters a state describable in terms of a wave function in a superposition, it is not simply the atom which enters that superposition but the entire universe containing that atom. From that moment onwards, there is one branch of the superposition containing an atom which has decayed and another branch of the superposition containing an atom which has not decayed. Each branch constitutes what we, aware only of the branch we are in, refer to as "the" universe. Since the decay of an atom has determinate consequences in Schrödinger's thought experiment, the death of the cat amongst those consequence, what happens when Hugh opens the chamber and discovers an alive or dead cat is that he discovers which branch of the superposition he is in. His opening of the chamber does not in itself either effect or affect the branching of the superposition.

We can understand Everett's account of quantum mechanics as implying that the universe itself has a wave function, and that this wave function is constantly evolving into a superposition, each branch of the superposition in turn branching. The inhabitants of this type of universe only ever experience one particular branch of the superposition, and since events along a single branch are completely determinate, inhabitants of this type of universe experience the physical world as determinate. It is because, however, there are a multitude of branches of the universal wave function, each branch constituting what the inhabitants of that branch would term "the" universe or world, that this theory is known as the many worlds theory of quantum mechanics.

If we interpret a measurement as an observation by a conscious observer, then depending upon the version of the many worlds theory we are adopting, a measurement can be conceived of either as that act which causes the universe to split or, more coherently, as that act which enables observers to discover on which branch of the superposition into which the universe has evolved they are located.

If a measurement is conceived of as that act which causes the universe to split, then a quantum system can be defined as the type of system which leads to the splitting of the universe when a measurement is performed upon it. This however seems to preclude our describing the universe itself as a quantum system.

If a measurement is conceived of as that act which enables observers to discover on which branch of the superposition into which the universe has evolved they are located, then it appears legitimate to describe the universe itself as a quantum system. Although it might be possible to identify smaller systems within a universe as quantum systems, it is not exactly clear how a boundary around such systems could be defined in a non-arbitrary way, since they are components of a system, the universe, which is itself quantum.

There are problems, given the many worlds account, as to how to understand interference effects such as those observed in the two slit experiment. According to what I have termed the more coherent version of the many worlds account, if one branch of the superposition into which the universe has evolved contains a quantum entity which has gone through slit A, then the other branch of this superposition contains a quantum entity which has gone through slit B. However, it can be shown experimentally that if a quantum entity only passes through one slit in the two slit experiment, no interference pattern is produced. This seems to imply, if we accept the coherent version of the many worlds account, that when an interference pattern is produced, it results from two separate branches of the superposition into which the universe has evolved interfering with each other.[30] The only way to avoid this conclusion is by reverting to the version of the many worlds theory according to which the universe only splits when a conscious observer makes a measurement on a quantum system. This allows the quantum entity to pass through both slits in the two slit experiment in a superposition localized to the quantum entity itself, before the universe as a whole splits when an observer looks at the screen to observe where the quantum entity has been detected.

Partly in response to these types of problem, a modified version of the many worlds theory was proposed, termed the many minds theory, and I will consider this theory in the following section.

(f) The Many Minds Theory

The many minds theory, which was first proposed by David Albert and Barry Loewer[31] in 1988, resembles the many worlds theory in some respects. The essential difference is that whereas in the many worlds theory the universe evolves into a superposition, in the many minds theory it is the mind of a conscious observer which evolves into a superposition. This difference can be illustrated with reference to the thought experiment involving Schrödinger's cat.

Let us again consider the moment at which our conscious observer Hugh opens the chamber in which Schrödinger's cat is contained. The quantum system contained within the chamber has evolved into a superposition, in one branch of which the cat is alive and in the other branch of which the cat is dead. Nonetheless, when Hugh opens the chamber, he observes a cat in a determinate state, either alive or dead.

According to the many worlds theory, the universe itself has evolved, or evolves at the moment that Hugh opens the chamber, into a superposition with two branches. In one branch, Hugh is confronted by an alive cat, in the other branch, Hugh is confronted by a dead cat.

Advocates of the many minds theory discount the idea that the universe evolves into a superposition and argue instead that when a conscious observer like Hugh is confronted by a quantum system in a two-branch superposition, a proportion of the

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[30] There is nothing in the many worlds theory as it stands which forbids two separate branches of the superposition into which the universe has evolved from interfering with each other. It is usually assumed, however, that once the universe has evolved into a superposition, the separate branches of the superposition have no further effect upon one another.

[31] Confer Albert and Loewer 1988.

minds of the conscious observer perceive one branch of the superposition, the remainder of the minds of the conscious observer perceive the other branch of the superposition. How many minds does a conscious observer have, in that case? A clue to the answer is contained in the name of this theory, the many minds theory, and the actual answer is that, according to this theory, a conscious observer has an infinity of minds.

The proportion of the observer's minds which perceive a particular branch of a superposition corresponds to what we would describe in standard quantum mechanics as the probability of finding a quantum entity in the state represented by that branch of the superposition. In the case of Schrödinger's cat, standard quantum mechanics informs us that there is a probability of a half that Hugh will find the cat alive when he opens the chamber. According to the many minds theory, what this actually implies is that half of Hugh's minds perceive the branch of the superposition in which the cat is alive. The other half of Hugh's minds perceive the branch of the superposition in which the cat is dead. Had standard quantum mechanics assigned a probability of a third to finding the cat alive, only one third of Hugh's minds would have perceived the branch of the superposition in which the cat is alive. The other two thirds of Hugh's minds would have perceived the branch of the superposition in which the cat is dead. Nonetheless, each of Hugh's minds, from its own point of view, observes a cat in a determinate state.

The many minds theory implies that when a quantum system evolves into a superposition, it remains in that superposition and never collapses back into a determinate state. However, if a conscious observer encounters a system in a superposition, any particular mind of the infinity of minds possessed by the observer only perceives one branch of the superposition, and therefore perceives the quantum system in a determinate state. On this account, we can describe the act by a conscious observer of observing a quantum system as a measurement of that system. However, an exact definition of a measurement is not vital in the many minds theory, since a quantum system remains in a superposition, even after it has been measured, whatever form that measurement takes. A quantum system, in this account, is therefore any system which can evolve into a superposition.

(g) The Spontaneous Localization Theory (GRW)

The final theory of quantum mechanics which I will consider appears comparatively mundane by comparison with some of the theories at which I have looked in the previous sections. The spontaneous localization theory, often referred to as GRW after the three physicists who first proposed it in 1985, G.C. Ghirardi, A. Rimini, and T.

Weber[32], postulates that although individual quantum entities around 10^{-11} m in size can and do exist in superpositions, the chances of objects composed of even a relatively small number of such entities existing in superpositions is so small as to be negligible.

Consider a single quantum entity. According to GRW, such an entity evolves according to Schrödinger's wave function for most of its existence. However, GRW stipulates that there is a very small probability at each moment at which a quantum entity exists that the wave function describing that entity will collapse in such a way that the entity will, at the moment that the collapse occurs, have a determinate position. After such a collapse, the entity will again continue to evolve according to Schrödinger's wave function. As so described, there is only a very small probability of finding a single quantum entity in a state of determinate position.

However, macroscopic objects, including the devices which we use to make measurements in experiments, are composed not of single quantum entities but of vast ensembles of such entities. If we consider for example a pointer on a measuring device, a pointer composed of, say, 10^{25} quantum entities, we can see that even if there is only a probability of 1 in 10^{25} that a particular quantum entity will undergo a wave function collapse at a particular moment of time, then the likelihood is that at least one quantum entity in the ensemble of quantum entities which compose the pointer will undergo a wave function collapse at that particular moment of time.

According to GRW, the effect of a single quantum entity in an ensemble of quantum entities undergoing a wave function collapse is, in effect, to collapse the wave function of the ensemble as a whole. In the case of the pointer on the measuring device, therefore, provided that the wave function of at least one quantum entity in the ensemble of quantum entities composing the pointer collapses at a particular moment of time in such a way that the entity in question has a determinate position, then the wave function of the entire pointer will collapse in such a way that the pointer has a determinate position. Given that at any particular moment of time, at least one of the quantum entities composing a macroscopic object like a pointer is likely to have a determinate position, we will almost always experience macroscopic objects like pointers as having determinate positions.

Interestingly Albert, who was originally doubtful about the viability of the GRW theory,[33] has more recently expressed support for the theory.[34] He gives a succinct description of GRW as follows.

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[32] Confer Ghirardi, Rimini, and Weber 1985, 1986.
[33] Confer Albert 1992.

> "Ghirardi, Rimini, and Weber's idea (the GRW theory) goes (roughly) like this: the wave function of any single-particle system almost *always* evolves in accordance with the linear deterministic equations of motion; but every now and then (once in something like 10^9 years), at random, but with fixed probability per unit time, the wave-function is suddenly multiplied by a narrow bell-shaped curve - a curve (more particularly) whose width is something on the order of the diameter of a single atom of one of the lighter elements - which has the effect of *localizing* it, of setting its value at zero everywhere in space except within a certain small region. The *probability* of this bell curve's being centered at any particular point x depends (in accordance with a precise mathematical rule) on the *wave-function* of the particle at the moment just *prior* to that multiplication. Then, until the next such "jump," everything proceeds as before, in accordance with the deterministic differential equations." (Albert 2001, p.148)

If we apply GRW to the Schrödinger's cat thought experiment, we can see that an atom in the radioactive sample will certainly evolve into a superposition, but almost as certainly this superposition will have no measurable effect at the level of the macroscopic Geiger counter which is composed of a vast number of atoms. The chance therefore of the Geiger counter entering into an overall superposition of states, let alone of the cat doing so, is virtually zero.

Measurement in the GRW theory of quantum mechanics, since it is carried out using large macroscopic objects, is invariably of determinate quantities. Although entities do indeed exist in superpositions, the indeterminate states implied by these superpositions are not detectable at the macroscopic scale, owing to the collapse mechanism postulated by GRW, namely the very small probability that any particular quantum entity in a superposition will undergo spontaneous localization and hence the very large probability that a macroscopic object composed of many quantum entities will undergo spontaneous localization. In GRW, therefore, measurement plays no part in causing a wave function to collapse, and hence measurement is no more than an intervention in a system to establish a determinate property of that system. In some sense, a system is quantum at any scale in GRW, since all systems are composed of quantum entities. However, any system composed of more than a few quantum entities will not exhibit the wave function behaviour which we might take to be characteristic of quantum systems.

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[34] Confer Albert 2001, p.149.

4 Reversible And Irreversible Evolution Of Quantum Entities

In the previous section, I have considered a number of different interpretations of quantum mechanics.[35] I will refer to these interpretations in assessing the implications of quantum mechanics for temporal metaphysics in chapter 7. Before turning my attention to these implications, however, I am going to examine another aspect of quantum mechanics which may also have implications for temporal metaphysics, namely whether a system[36] described in quantum mechanical terms exhibits reversible behaviour.

We saw in section 2 of the current chapter that quantum mechanics provides us with two ways of describing the behaviour of a system. It is possible to describe the evolution[37] of a system in terms of its quantum mechanical wave function. In this context, the Schrödinger equation is the equation used to represent the dynamical evolution of a quantum system.[38] It is also possible to describe the behaviour of a system when a measurement[39] is made upon it. Whilst the wave functions which describe quantum systems display evolution into superpositions,[40] when we come to make a measurement upon a quantum system we only ever measure determinate properties of that system. The wave function of a radioactive atom, for example, can

[35] I have referred to many of the interpretations as theories "to allow for the possibility of not reproducing all the empirical predictions of QM" (Redhead 1989, p.98).

[36] In general terms, a system is some region of a universe around which a theoretical boundary is drawn. Analysis is then largely confined to the region within this boundary, though some consideration may be given to flows (of matter, energy, information, and so on) across this boundary. Quantum mechanics usually, but not exclusively, focuses upon systems of the order of 10^{-11} m in size, such as atoms and the components of atoms.

[37] The evolution of a system is the way in which it changes over time. From the static block universe, the growing block universe or the growing determinacy points of view, a description of the evolution of a system over two moments would be a description of how the properties of one of the temporal parts constituting the system differ from the properties of an adjacent temporal part. From a presentist point of view, a description of the evolution of a system over two moments would be a description of how the properties of the system existing at one moment differ from the properties of the same system existing at the next moment. Note that only in a presentist account is the system undergoing non-incremental existential change.

[38] As noted in footnote 6, the Schrödinger equation is time symmetric under Wigner transformations but is not time reversible under $t \rightarrow -t$. It should also be noted that the solutions to the equation need not be time symmetric, and generally are not.

[39] As became apparent in section 3 of the current chapter, what precisely constitutes a measurement is not straightforward in quantum mechanics. In simple terms, it is an intervention in a system performed from outside the system, and I will assume that no more than this is meant by the term in the current section.

[40] There is an underlying question here as to whether every element of a physical theory has a counterpart in physical reality. I formulate the question using Redhead's terminology (Redhead 1989, p.71). He himself draws the terminology from Einstein, Podolsky and Rosen 1935. In relation to quantum mechanics, we can ask whether the evolution of superpositions in the representation of quantum systems indicates a superposition of those quantum systems themselves. Since superpositions are held to arise precisely when a quantum system is not being measured, there is no way of ascertaining whether the system itself is in a superposition when not being measured, unless a physically realized superposition has detectable consequences beyond the superposition state. This is one of the issues which Einstein, Podolsky and Rosen are addressing.

evolve into a superposition representing decayed and undecayed states. We only ever measure the atom, however, as either decayed or undecayed at a particular moment of time. This might suggest that the act of measurement irreversibly changes the state of a quantum system, shifting it out of what I will term a *superposition state*, that is, a state which is associated with no determinate observable properties, and into what I will term an *observable state*, that is, a state which is associated with determinate observable properties.[41]

I will examine in chapter 7 what possible implications we might derive from the conclusion that the transition of a quantum system from a superposition to an observable state, as a consequence of making a measurement on the quantum system, is irreversible. However, the claim that the transition of a quantum system from a superposition into an observable state *is* irreversible is a controversial one. I will therefore begin by examining why the shift from a superposition to an observable state might appear irreversible.

(a) An Argument For The Claim That Measurement Of A Quantum System Induces An Irreversible Change In That System

I will first consider an argument in favour of assuming irreversibility given by Roger Penrose.[42] In the following passage, Penrose uses the bold letter **R** to denote state-vector reduction, the mathematical correlate of performing a measurement on a quantum entity. **R** is therefore the mathematical representation of the act of performing a measurement. **U** denotes the evolution of the Schrödinger equation, the mathematical correlate of the evolution of the wave function of a quantum entity.[43]

> "There seems to be a prevailing view that **R** ... should be time-symmetric. Perhaps this view arises partly because of a reluctance to take **R** to be an actual 'process' independent of **U**, so the time-symmetry of **U** ought to imply time-symmetry also for **R**." (Penrose 1989, p.354)

Penrose is acknowledging that some theorists regard the act of performing a

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[41] If we are measuring one of a pair of non-commuting properties, Heisenberg's uncertainty principle indicates that a determinate measurement of one of the properties, position for example, will render indeterminate the other of the pair of non-commuting properties, momentum in the case of position, if we were to try to measure it at the same time.

[42] Penrose 1989, pp.354-359.

[43] See Beiser 1987, chapter 5, for a detailed explanation of the mathematical representation of the evolution and measurement of quantum entities.

measurement on a quantum entity as time-symmetric, and he is suggesting that their view may derive from an unwillingness to distinguish a measurement *per se* from the time-symmetric evolution of a quantum entity as embodied in its wave function.

However, Penrose himself considers that we can distinguish, on the one hand, the act of performing a measurement on a quantum entity from, on the other hand, the evolution of a quantum entity when that entity is not being measured. His argument is, in effect, that the act of performing a measurement is represented as a mathematical procedure carried out *upon* the mathematical representation of a wave function, and that these different mathematical representations embody a genuine difference in the physical reality which they are designed to represent.

Furthermore, Penrose considers that, whilst on the one hand the mathematical representation of the evolution of a wave function is symmetric with respect to the mathematical representation of the time co-ordinate in the wave function, on the other hand the mathematical procedure which represents the act of performing a measurement on a quantum entity is not symmetric with respect to mathematical representation of the time co-ordinate in the wave function of the entity. Once again, the implication is that the temporal symmetry of the mathematical representation of the evolution of a wave function, and the temporal asymmetry of the mathematical representation of a measurement on a quantum entity, reflect a genuine difference in the physical reality which the two mathematical representations are intended to represent.

Penrose sets out to illustrate that the mathematical representation of a measurement on a quantum entity is time-asymmetric by means of an experiment which I shall term the half-silvered mirror experiment. The experiment requires a source of quantum entities, a half-silvered mirror, and a detector of quantum entities. In the version of the experiment which Penrose describes, the quantum entities are photons, and hence a lamp is used as the source, whilst the photons are detected by a photo-cell. The apparatus is illustrated in figure 6.3 below.

The half-silvered mirror is tilted at an angle of 45° to the line between the lamp and the photo-cell, as illustrated. The experiment consists in allowing the lamp to emit a quantum entity, a photon, at random moments directly towards the photo-cell. The emission of the photon is registered at L and the detection of the photon is registered at P. The half-silvered mirror is designed to reflect exactly half of all the photons which reach it towards the point A on the laboratory wall and to transmit the other half towards the point P on the photo-cell.

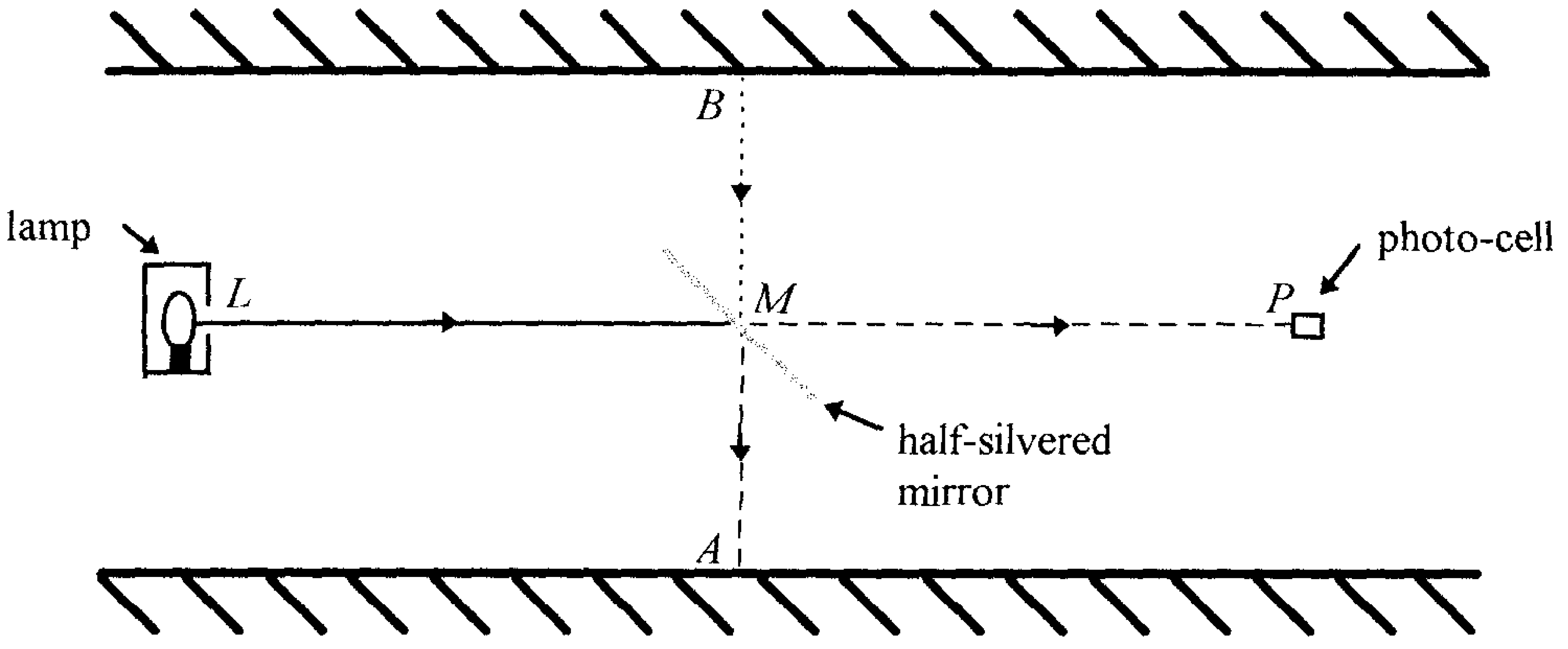

Fig. 6.3 The apparatus for the half-silvered mirror experiment consists of a lamp, a half-silvered mirror, and a photo-cell. The laboratory walls are shown shaded at the top and bottom of the diagram. The diagram is based on the one given by Penrose 1989, p.357.

Let us consider the situation from the point of view of a single photon. Before[44] the photon reaches the mirror, its evolution is describable in terms of a wave function which relates to a single trajectory, that between L and M. After the photon reaches the mirror, however, its evolution must be described in terms of a wave function which relates to two different trajectories, the two possible paths which the photon can take, the path between M and P, and the path between M and A. The part of the wave function which relates to the path of a transmitted photon between M and P has an amplitude[45] of $1/\sqrt{2}$, and the part of the wave function which relates to the path of a reflected photon between M and A has an amplitude of $1/\sqrt{2}$.

We say that the wave function used to describe the photon after the photon reaches the mirror is a superposition. This is because the wave function required to describe the evolution of the photon as a whole is composed of more than one part, the part which describes the evolution of a reflected photon and the part which describes the evolution of a transmitted photon.

The amplitudes of the two parts of the photon's wave function after the photon has reached the mirror imply that, once a photon has been emitted from A, the probability of subsequently detecting a photon at P is 1/2 and the probability of subsequently not detecting a photon at P is also 1/2. This is because the probability of detecting a quantum entity along a particular trajectory is given by the square of the

[44] I will assume, initially, a temporal orientation according to which the emission of the photon from the lamp precedes its transmission or reflection by the half-silvered mirror.

[45] An amplitude is associated with each part of a wave function. In simple terms, when the modulus of an amplitude $\sqrt{P}$ associated with a particular part of a wave function is squared, the resultant value P is the probability of finding the entity described by the wave function in the state described by that part of the wave function with which the amplitude $\sqrt{P}$ is associated.

modulus of the amplitude of that part of the wave function which defines the trajectory. In the case we are considering, the square of the modulus of the amplitude is $|(1/\sqrt{2})|^2 = 1/2$. As Penrose puts it, the quantum mechanical answer to the question "Given that *L* registers, what is the probability that *P* registers?" is "one half" (Ibid., p.358).

Penrose next invites us to consider the same experiment with the orientation of time reversed. Suppose that the presence of a photon is registered at *P*. Since the orientation of time is reversed, the evolution of the photon is describable in terms of a wave function which relates to the single trajectory between *P* and *M*. Tracing back through time, the evolution of the photon beyond the trajectory between *P* and *M*, that is, beyond the point at which the photon reaches the mirror, must be described in terms of a wave function which relates to two different trajectories, the two possible paths which the photon can take, the path between *M* and *L*, and the path between *M* and *B*, where *B* is a point on the laboratory wall opposite to the laboratory wall on which the point *A* is located. The part of the wave function which relates to the path of a transmitted photon between *M* and *L* has an amplitude of $1/\sqrt{2}$, and the part of the wave function which relates to the path of a reflected photon between *M* and *B* has an amplitude of $1/\sqrt{2}$. Squaring as before, we obtain two probabilities, each with the value 1/2. However, Penrose advises caution.

> "[W]e must be careful to note what questions these probabilities are the answers to. They are the two questions, 'Given that L registers, what is the probability that P registers?', just as before, and the more eccentric question, 'Given that the photon is ejected from the wall at B, what is the probability that P registers?'" (Ibid., p.358)

Whilst the probabilities offered as answers to these two questions are what we might expect, Penrose points out that "neither of these questions is the *time-reverse* of the one we asked before" (Ibid., p.358). The time reverse of the original question, "Given that *L* registers, what is the probability that *P* registers?", is the question "Given that *P* registers, what is the probability that *L* registers?" (Ibid., p.358). The correct answer to this question, Penrose suggests, is "one".

> "If the photo-cell indeed registers, then it is virtually certain that the photon came from the *lamp* and not from the laboratory wall! In the case of our time-

reversed question, the quantum-mechanical calculation has given us *completely the wrong answer*!" (Ibid., p.358)

Penrose interprets this result as implying that the mathematical procedure which represents the act of performing a measurement on a quantum entity is not invariant under reversal of the orientation of time.

"The implication of this is that the rules for the **R** part of quantum mechanics simply cannot be used for such reversed-time questions. If we wish to calculate the probability of a *past* state on the basis of a known *future* state, we get quite the wrong answers if we try to adopt the standard **R** procedure of simply taking the quantum-mechanical amplitude and squaring its modulus. It is only for calculating the probabilities of *future* states on the basis of *past* states that this procedure works - and there it works superbly well! It seems to me to be clear that, on this basis, the procedure **R** *cannot be time-symmetric* (and, incidentally, therefore cannot be a deduction from the time-symmetric procedure **U**). (Ibid., p.359)

The half-silvered mirror experiment appears to demonstrate that the mathematical procedure which represents the act of performing a measurement on a quantum entity would give us the wrong probabilities if applied in a time-reversed situation. If we accept that the mathematical procedure in question, state vector reduction, reflects the physical reality which it is designed to represent, we can conclude that the act of performing a measurement on a quantum entity brings about an irreversible change in that quantum system.[46] Are we justified in concluding, therefore, on the basis of the half-silvered mirror experiment, that whenever a measurement is made on a quantum entity, an irreversible evolution in the behaviour of the quantum entity ensues? The research to which I turn now suggests not.

[46] It is worth noting that whilst the mathematical representation of the act of measurement on a quantum entity gives the wrong results when applied in a time-reversed situation, this does not prove that measurement itself is irreversible. It could be that the mathematical representation currently in use in quantum mechanics fails to embody the reversibility of measurement. However, it is also worth noting that a similar problem arises in relation to all mathematical representations of physical conditions. Those conditions which appear to be time-reversal invariant in one mathematical representation, for example in relativity theory, might be considered irreversible in an alternative representation. I will leave this consideration to one side.

(d) An Argument Against The Claim That Measurement Of A Quantum System Induces An Irreversible Change In That System

In a paper published in 1964 the physicists Aharanov, Bergmann and Lebowitz argue that the irreversibility brought about by measurement of a quantum system is only apparent.

> "We argue that this time asymmetry is actually related to the manner in which statistical ensembles are constructed." (Aharanov, Bergmann and Lebowitz 1964, p.1410)

They go on to demonstrate that it is possible to construct ensembles in which the process of measurement introduces no time asymmetric element. This is done by selecting both the initial and final states of the system so as to delimit the sample. It is the selection of the required final states of the system, as well as the more usual selection of its initial states, which produces a time symmetric expression for the probability of obtaining a particular value in the course of measurement. In other words, the probability function produces the correct value of either the following or the preceding state, depending on whether we run the sequence of measurements from earlier to later or from later to earlier. Therefore, we cannot deduce whether one measurement comes before or after another from its outcome.

Although Aharanov, Bergmann and Lebowitz go on to demonstrate that time symmetric measurements can be extended to ensembles where we are restricted to either pre-selection or post-selection by means of "coherence destroying" manipulations, they go on to propose a postulate "which asserts that ensembles with unambiguous probability distributions may be constructed on the basis of pre-selection only" (Aharanov, Bergmann and Lebowitz 1964, p.1410). They conclude that this postulate derives from the time irreversibility of the universe as a whole, rather than from the laws of quantum mechanics, and therefore assert that the laws of quantum mechanics are in fact time symmetric.

The results of Aharanov, Bergmann and Lebowitz should not necessarily be viewed as flatly contradicting Penrose's argument. Aharanov, Bergmann and Lebowitz allow that measurements on quantum systems will exhibit irreversibility where the sample from which the behaviour of a quantum system is deduced is not selected "on the basis of required outcomes of specified initial and final observations" (Aharanov, Bergmann and Lebowitz 1964, p.1410). However, whereas it might appear from

Penrose's argument that it is the formal representation of quantum mechanics itself which embodies temporal irreversibility, the thesis of Aharanov, Bergmann and Lebowitz implies that the irreversibility which is apparently disclosed in the measurement of quantum systems is a reflection of the temporal asymmetry of our universe *per se*, rather than specifically of quantum mechanics.

> "We are thus confronted with an indubitable asymmetry in time direction. It remains to discuss whether this asymmetry is a property of microphysics proper or whether it represents the intrusion of the macroscopic universe on the microscopic scene. Granting that this question does not lend itself to straightforward logical analysis, it appears to us that the construction of ensembles in the real physical universe is a macroscopic operation and that it depends on the realities of the universe as a whole." (Aharanov, Bergmann and Lebowitz 1964, p.1416)

Even allowing for the results demonstrated by Aharanov, Bergmann and Lebowitz, measurement performed on a quantum system (provided it has not been specially prepared to ensure reversibility) remains a means of revealing an underlying temporal asymmetry, leaving aside whether that asymmetry has a macroscopic or microscopic origin. In the next section, I will examine how we might make use of measurements on quantum systems in establishing the temporal orientation of a universe.

6 Conclusion

We have seen in this chapter that the mathematical procedures used to represent the act of performing a measurement upon a quantum system can be interpreted as indicating an irreversible change in the mathematical representation of a quantum system as a wave function.[47] However, we have also seen that the irreversibility reflected in the measurement of quantum systems does not appear to be attributable to the formal representation of quantum mechanics per se, since it is possible to prepare ensembles of quantum mechanical systems in such a way that time-symmetric measurements can be

[47] Heisenberg formulated an alternative mathematical representation of quantum systems to Schrödinger. Heisenberg represents quantum systems by means of matrices rather than by means of wave functions. Nonetheless, the mathematical procedures used to represent the act of performing a measurement upon a quantum system in Heisenberg's representation can also be interpreted as representing an irreversible change, since the application of the procedures in Heisenberg's representation produces the same probabilities in the half-silvered mirror experiment as the application of the procedures in Schrödinger's representation.

carried out upon them. This may suggest that the irreversibility apparent in the measurement of quantum systems is a reflection of an inherent direction of time in the universe as a whole.

The irreversibility made apparent during measurement of a quantum system provides us with a means of establishing a temporal orientation in a structurally simple universe. If such a universe conforms to the universal measurement law, the law which was postulated as the quantum mechanical equivalent of the second law of thermodynamics, then we are able to establish a sequence of global time slices in such a universe along which the measure count sum of the universe always increases. Such a universe can be interpreted in terms of a physically distinguished present metaphysics, since at least one sequence of global time slices is defined within it, namely that sequence along which the measure count sum of the universe increases.

It was shown that, if we assume that one consequence of being time-like is that the measure count sum associated with points along a time-like curve in a particular direction should always increase, then a paradox arises for a closed time-like curve of the type which arises in Gödel's rotating universes. This paradox is similar to the paradox which arises if we assume that the entropy of the universe associated with points along a closed time-like curve in a particular direction should always increase.

I concluded the chapter by considering whether it is possible to give an account of the direction of time in terms of causal ordering.

In the course of this chapter, I have made extensive use of the concept of a measurement upon a quantum system, but I have not as yet clarified what constitutes such a measurement, nor indeed what constitutes a quantum system. This will be the first task in the next chapter, as a prelude to considering whether it is possible to formulate a physical theory which is consistent with our current theories of physics, but which suggests a candidate for the physical correlate of our experience of the passage of time compatible with some version of a physically distinguished present temporal metaphysics rather than with a static block universe temporal metaphysics.

7

Implications Of Quantum Mechanics For Temporal Metaphysics

1 Introduction

We saw in the previous chapter that Aharanov, Bergmann and Lebowitz (ABL) argue that the formal mathematical representation of the measurement of a quantum system is not intrinsically irreversible. "[T]he basic laws of quantum physics, including those referring to measurements, are as completely time symmetric as the laws of classical physics" (ABL 1964, p.1410). It nonetheless appears that measurement of a quantum system can make explicit an underlying temporal irreversibility, although it remains unclear at what level that irreversibility is located, depending upon whether one is persuaded by Penrose's argument or by ABL's.

In the current chapter, therefore, I am going to investigate whether it is possible to use measurement of quantum systems as a means of demonstrating that a universe containing closed time-like curves is incompatible with the underlying temporal irreversibility which measurement of a quantum system makes explicit in our universe, even though that universe may be compatible in principle with the formal representation of the measurement of a quantum system.

Given that measurement of a quantum system is a causal interaction, the question arises as to whether the direction of time can be explained in terms of the direction of causality per se, rather than in terms specifically of quantum interactions. I therefore conclude the chapter by considering the causal theory of time order.

2 Establishing A Temporal Orientation In A Structurally Simple Universe By Performing A Measurement Upon A Quantum System

I am going to consider the arbitrary universe U_0 which was defined in chapter 5.[1] U_0 is a structurally simple universe, one which does not contain closed time-like curves. I will assume as before that we can define a sequence of global time slices within U_0[2] and that U_0 is a block universe only in the sense that entities contained within it are composed of temporal parts, a universe which is compatible with a growing block universe metaphysics or a growing determinacy metaphysics, as well as with a static block universe metaphysics.

Suppose that we conduct the quantum two slit experiment as described in section 2 of chapter 6, the version of the experiment in which we use a source which emits quantum entities, during some arbitrary sequence of ten time slices, moments of time, which we label t_{i+1} to t_{i+10}. Suppose that the source emits a quantum entity at the moment t_{i+1} and that the quantum entity is detected at the screen at the moment t_{i+10}. During the sequence of moments between t_{i+1} and t_{i+10}, the behaviour of the quantum entity is describable only in terms of its wave function. When the quantum entity is detected at the moment t_{i+10}, its behaviour is no longer describable in terms of the same wave function that described it previously.

Assuming that measurement induces an irreversible transition in a quantum system from a superposition state to an observable state, we can conclude that the time slice t_{i+10}, which contains the detection of the quantum entity, must occur after the time slice t_{i+1}, which contains the emission of the quantum entity. Assuming that the moments t_{i+2} to t_{i+9} lie in an ordered[3] sequence between t_{i+1} and t_{i+10}, we can deduce that the whole sequence of moments are temporally ordered. The two slit experiment therefore gives us a means of establishing a temporal orientation along a sequence of moments, as illustrated in figure 7.1.

Given that the two slit experiment can be performed for any sequence of time slices in U_0, it is theoretically possible to establish a temporal orientation for the entire sequence of time slices in the universe.

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[1] Confer chapter 5, section 4.

[2] It may be that a number of different sequences of global time slices can be defined in U_0. I will assume initially that there is only one sequence along which the temporal parts of a quantum two slit experiment can be located. I will eventually need to consider whether this is a valid assumption.

[3] The (non-temporal) ordering of the sequence is assumed on the grounds that an ordered sequence of global time-slices have been defined within U_0.

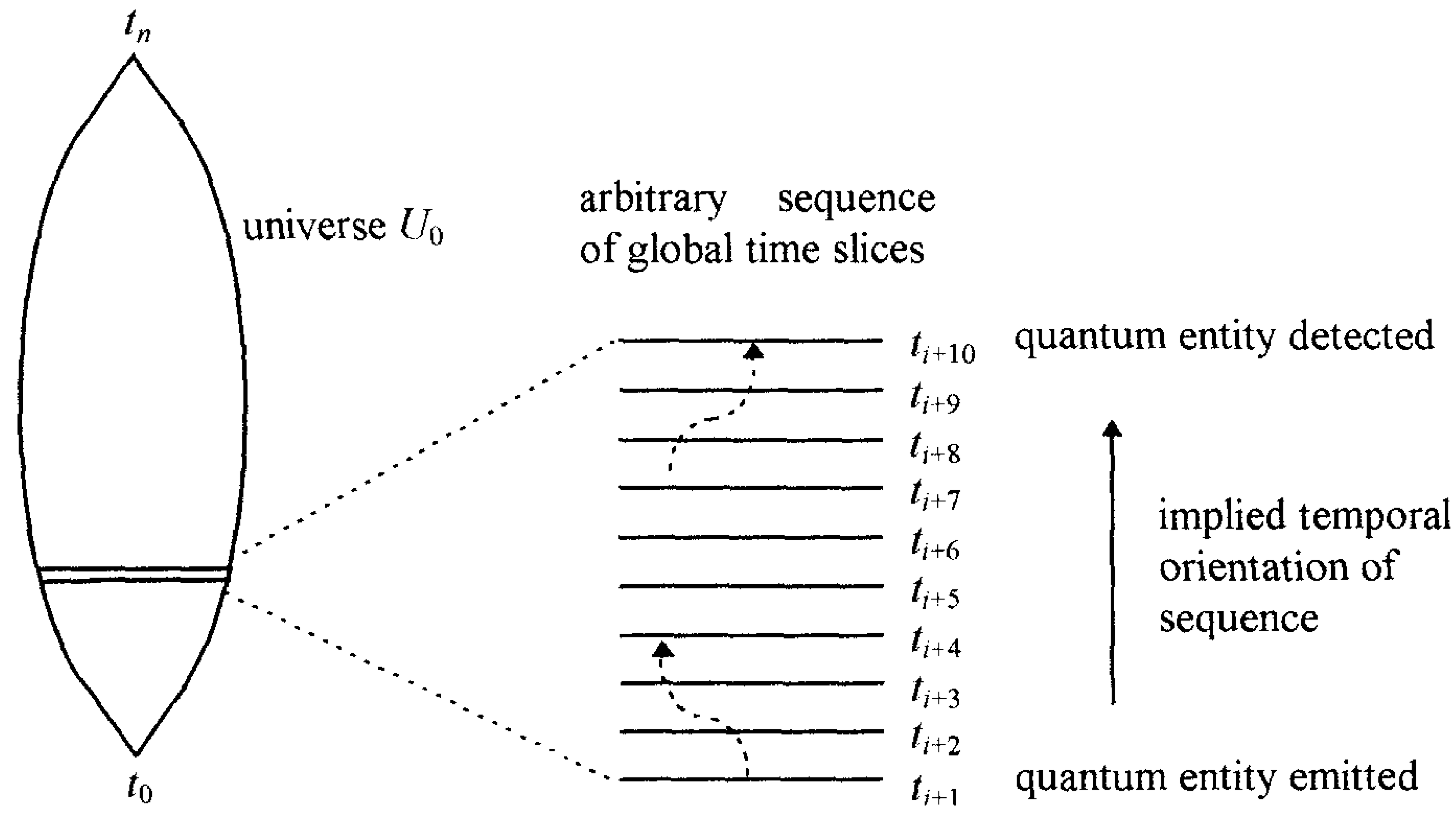

Fig. 7.1 A two slit experiment involving the emission and detection of a quantum entity is conducted in the structurally simple block universe U_0, shown on the left. The experiment is conducted during some arbitrary sequence of global time slices t_{i+1} to t_{i+10} shown on the right. The emission and detection of the quantum entity imply a temporal orientation of the sequence of time slices. The representation of the universe is based on the representation of a universe given by Penrose 1989, p.325.

We need to observe, however, that there is no law extant in quantum mechanics, equivalent to the second law of thermodynamics, which implies that the temporal orientation of the universe over its entire sequence of global time slices must remain constant. Therefore, although the two slit experiment allows us to determine the temporal orientation of a short sequence of time slices, this determination in itself does not guarantee that the temporal orientation so established applies to the entire sequence of time slices contained in U_0.

Would we be justified in postulating a quantum mechanical law, equivalent to the second law of thermodynamics, and if so, what form would that law take? Recall the formulation of the second law of thermodynamics employed in chapter 5.

> "The only changes that are possible for an isolated system are those in which the entropy of the system either increases or remains the same. Changes in which the entropy decreases will not happen." (Halliday and Resnick 1988, p.525)

If we consider the origins of the second law of thermodynamics, we can observe that the law is formulated on the basis of a finite number of observations of systems which only approximate to isolated systems. In the course of observing such systems, it has been found that entropy has always either increased or broadly remained the same. The process by which the second law is arrived at therefore appears to be essentially an inductive one, moving from a finite number of observations of particular quasi-isolated systems to a claim about isolated systems in general.[4]

Since it is impossible in practice to totally isolate a system from its surroundings, a universe, which by definition has no surroundings, appears to be the only genuinely isolated system. Therefore we can rewrite the second law, substituting "universe" for "isolated system", to give us the following.

> The only changes that are possible for a universe are those in which the entropy of the universe either increases or remains the same. Changes in which the entropy decreases will not happen.[5]

Can an equivalent law be formulated for quantum mechanics? Provided that we accept that experiments such as the two slit experiment and the half-silvered mirror experiment are genuinely irreversible, then we are in no worse a position in terms of our evidence for a law of irreversibility on the basis of quantum mechanics than we are in terms of our evidence for the second law of thermodynamics.

In an attempt to formulate a law which expresses the direction of time in terms of quantum mechanics and which resembles the second law of thermodynamics, I will begin by defining a quantity which I will term the *measure count*.[6]

> The measure count of a quantum system[7] at a particular global time slice is the number of times a measurement has been performed upon that quantum system

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[4] A Popperian, who would be less concerned with the particular process by which the second law was arrived at, would probably prefer to describe the law as a bold hypothesis which has yet to be falsified. Confer Popper 1959.

[5] This formulation is equivalent to the formulation at which Rudolf Clausius arrived in 1865, when he reformulated the first and second laws of thermodynamics in cosmological terms.

[6] A potential equivalent in quantum mechanics of the entropy of thermodynamics is the quantity $-\mathrm{Tr}U\ln U$ proposed by von Neumann, where U is a statistical operator. Von Neumann indicates an interesting feature of this entropy expression. "Although our entropy expression, as we saw, is completely analogous to the classical entropy, it is still surprising that it is invariant in the normal evolution in time of the system (process 2), and only increases with measurements (process 1) - in the classical (where the measurements in general played no role) it increased as a rule even with the ordinary mechanical evolution of the system." (von Neumann 1955, p.398-9) Von Neumann defines process 1 and process 2 as follows. In process 2, H is the energy operator, t is time, and H is independent of t.

Process 1: $$U \rightarrow U' = \sum_{n=1}^{\infty} (U_{\phi_n}, {}^{\phi}n) P_{[\phi_n]}$$

Process 2: $$U \rightarrow U_t = e^{-i\frac{2\pi}{h}.tH}\, U e^{i\frac{2\pi}{h}.tH}$$

[7] Note that I define the measure count in terms of a quantum system. What I have referred to as quantum entities, entities such as photons or electrons, are definable as quantum systems, and I will therefore sometimes refer to such entities as quantum systems.

up to[8] that particular global time slice.

It will be necessary to assess whether the postulation of this quantity is justified. Let us first, however, consider the postulated law, which is based upon the concept of the measure count, and which I will term the *measurement law*.

> The only changes that are possible for a quantum system are those in which the measure count of the system either increases or remains the same. Changes in which the measure count decreases will not happen.

The measure count and the measurement law taken together embody the notion that once a measurement has been performed upon a quantum system, an irreversible change in the evolution of the system ensues. Therefore, a measurement cannot be undone.

The measure count, which is assigned a numerical value without units, is conceived of as follows. Suppose that a quantum system has had no measurements made upon it. Its measure count is zero. After a measurement is performed upon it for the first time, its measure count becomes one. If it were possible to perform a measurement on a quantum system which reversed the effect of the first measurement, then it would be legitimate to deduct one from the measure count of the system, so that its measure count would return to zero. However, if it is assumed that measurement causes an irreversible change in the evolution of a quantum system, the effect of performing a second measurement upon the quantum system is to increase its measure count to two.

Let us consider what happens to the measure count of a quantum entity such as a photon when we perform a two slit experiment during some arbitrary sequence of global time slices t_{i+1} to t_{i+10} defined in the universe U_0. If we assume that no measurement has been performed upon the quantum entity prior to its emission at t_{i+1}, then we can assign it a measure count of zero at t_{i+1}. When the quantum entity is detected at t_{i+10}, its measure count becomes one.

There is still a problem, however, if we attempt to equate the increase in the measure count of a quantum entity such as a photon with an increase in the measure

[8] The definition of the measure count assumes a temporal orientation to the universe in the phrase "up to". We could substitute the phrase "in universal simultaneity hyperplanes before and including" for the phrase "up to".

count of the universe as a whole. Whilst I have deliberately left vague what constitutes a measurement, I have suggested that in simple terms it is an intervention in a system performed from outside the system.[9] We cannot simply assign a measure count to the universe, therefore, since in the case of the universe there is no "outside" from which an intervention could be performed.[10] Instead, I will define the *measure count sum* of the universe as follows.

> The measure count sum of a universe at a particular global time slice is the sum of the measure counts of all the quantum systems comprising that universe at that particular global time slice.

Even this definition leaves us with a problem, namely what constitutes a quantum system. We could, for example, define a quantum system as the entire contents of a universe apart from one atom. A measurement would then be deemed to be made when the atom "intervened" in some way in the rest of the universe. This example illustrates that the definition of what constitutes a quantum system is going to depend upon how we define a measurement. The definition of a quantum system as the entire

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[9] Confer chapter 6, section 3.

[10] The situation here is rather like the situation faced by proponents of an interventionist account of irreversibility in the realm of thermodynamics, as was pointed out to me by Michael Redhead. In the context of an analysis of spin-echo experiments and the implications of these experiments for the second law of thermodynamics, Ridderbos and Redhead (1998) make the following observation.

> "Since an isolated system will retain its coherence, the only way to account for nonequilibrium behavior is to focus on the fact that no physical system can be completely isolated from its environment. The origin of irreversibility is then seen to lie in the interaction between a system and its environment." (Ridderbos and Redhead 1998, p. 1257)

> This approach generates a potential problem when we consider the universe as a whole.

> "Since the universe itself does not have an environment to interact with, it follows that its entropy must be constant in time. Is not this in contradiction with what cosmologists standardly describe as the cosmic entropy increase?" (Ridderbos and Redhead 1998, p. 1261)

Ridderbos and Redhead address this problem by invoking a distinction between coarse-grained and fine-grained definitions of entropy, allowing that whilst entropy defined in coarse-grained terms can increase, this does not contradict "a fine-grained entropy which remains constant for the universe as a whole" (Ridderbos and Redhead 1998, p. 1262).

If measurement of a quantum system is defined as an intervention in a system performed from outside the system, then a problem, parallel to the problem described by Ridderbos and Redhead, arises in relation to measurement of the universe as a whole, regarded as a quantum system since, once again, "the universe itself does not have an environment to interact with".

It is interesting to speculate to what extent solutions to this problem with the measurement of quantum systems might resemble in their structure the solution offered by Ridderbos and Redhead to the problem for an interventionist account of irreversibility in the realm of thermodynamics. However, for the purposes of this thesis I will only indicate the existence of the problem without attempting to solve it.

contents of a universe apart from one atom, for example, would only be viable if an interaction of an atom with some other entity in the universe containing the atom counted as a measurement upon the entire system apart from the atom, rather than upon the atom. How precisely one defines a measurement and how therefore one defines a quantum system is going to depend upon which interpretation of quantum mechanics one adopts. Rather than select a particular interpretation, I will employ in what follows a concept of measurement which is broadly compatible with most of the interpretations of quantum mechanics which I discussed in chapter 6.

I assume that, in the two slit experiment, detection of a quantum entity such as a photon at a screen constitutes a measurement of a quantum system. I therefore assume that performing the two slit experiment for a single quantum entity has the effect of increasing the measure count of that entity by one. Suppose that in U_0 no measurements upon quantum systems are made other than by conducting the two slit experiment. At t_{i+1}, three separate two slit experiments begin, and at t_{i+10}, three quantum entities are detected at three separate screens. According to the definition of the measure count sum, the measure count sum of the universe at t_{i+10} is three more than the measure count sum of the universe at t_{i+9}. The measure count of each quantum entity in each of the three two slit experiments is one greater at t_{i+10} than it was at t_{i+9}.

I then propose that the temporal orientation established in any of the three two slit experiments, in the situation just described, is the temporal orientation not just of the sequence of time slices during which the experiments were conducted, but also the temporal orientation of the universe U_0 as a whole, the temporal orientation, that is, of the entire sequence of time slices contained in U_0. If this is the case then the quantum two slit experiment is capable of fulfilling much the same role as Einstein's signalling technique.

I assumed that the structurally simple universe U_0, one which contains no problematic space-time structures such as closed time-like curves, is one in which we are able to define a sequence of global time slices. Suppose now that the following conditions hold in U_0.

(M1) A sequence of global time slices can be identified in U_0 such that the time slice with the lowest measure count sum and the time slice with the highest measure count sum are at opposite ends of the sequence.

(M2) For any two adjacent global time slices in U_0, the time slice which is nearer to the time slice with the highest measure count sum has either the same or a higher measure count sum than the time slice which is further from the time slice with the highest measure count sum.

These two conditions, if they obtained in U_0, would constitute an ordering of the global time slices in U_0 in terms of the measure count sum.

3 The Paradox Of Measure Count Sum Increase Along A Closed Time-Like Curve

Equipped with the quantum two slit experiment, the concepts of the measure count and the measure count sum, and the measurement law, it is possible to demonstrate that a paradox arises on a closed time-like curve equivalent to the paradox which arose when we considered entropy increase around such a curve. All that is required is that we substitute the measure count for the entropy of a closed system, and replace Einstein's signalling technique with the two slit experiment.

Consider some arbitrary point P_1 on a closed time-like curve. Let us suppose that a quantum entity is emitted at P_1 and that this quantum entity has the measure count m_{11}. The measure count sum of the universe as a whole at this moment of time is M_1. The point P_1 is therefore associated with a measure count sum M_1.

Let us assume for convenience that the only measurements on quantum entities in the universe containing the closed time-like curve we are considering are made at points on that particular closed time-like curve, and that no measurements on quantum entities have been made prior to the emission of the quantum entity at P_1. We can therefore deduce that the measure count sum of the universe, M_1, is equivalent to the measure count of the quantum entity emitted at P_1, and that both of these are equal to zero.

$$M_1 = m_{11} = 0$$

The quantum entity emitted at P_1 passes through a barrier containing two slits, and at the point P_2 on the closed time-like curve, the quantum entity is detected. The measure count of the quantum entity increases by one to m_{12}, and the measure count sum of the universe likewise increases by one to M_2. The point P_2 is therefore associated with a measure count sum M_2, where M_2 is as follows.

$$M_2 = m_{12} = 1$$

Since M_2 is greater than M_1, we can deduce that P_2 lies after P_1. This deduction is based on the assumption that performing an act of measurement on a quantum system allows us to establish the temporal orientation of the universe.

We can repeat the double slit experiment to establish that P_3 lies after P_2. Assuming that a new quantum entity is emitted at P_2 and detected at P_3, the measure count of this quantum entity increases from m_{21} at P_2, equal to zero, to m_{22} at P_3, equal to one. The measure count of the quantum entity emitted in the previous experiment remains at one, and needs to be taken into account when calculating the measure count sum of the universe as a whole. Thus we can infer that P_3 is associated with a measure count sum M_3, where M_3 is as follows.

$$M_3 = m_{12} + m_{22} = 2$$

We can continue to associate measure count sums with points along the time-like curve in this fashion. Because, however, the time-like curve is closed, we will in theory eventually reach an arbitrary point P_n located a short time before P_1, the point from which we started. We should be able to infer that P_1 is associated with a measure count sum M_{n+1}, where M_{n+1} is defined as follows.

$$M_{n+1} = \sum_{1}^{n} m_{i2} = n$$

This inference however conflicts with our original assumption that the point P_1 is associated with the measure count sum M_1, which was equal to zero. Hence, just as the application of Einstein's signaling procedure along a closed time-like curve led to a paradox, so the application of the two slit experiment along a closed time-like curve leads to a similar paradox. The situation is illustrated in figure 7.2.

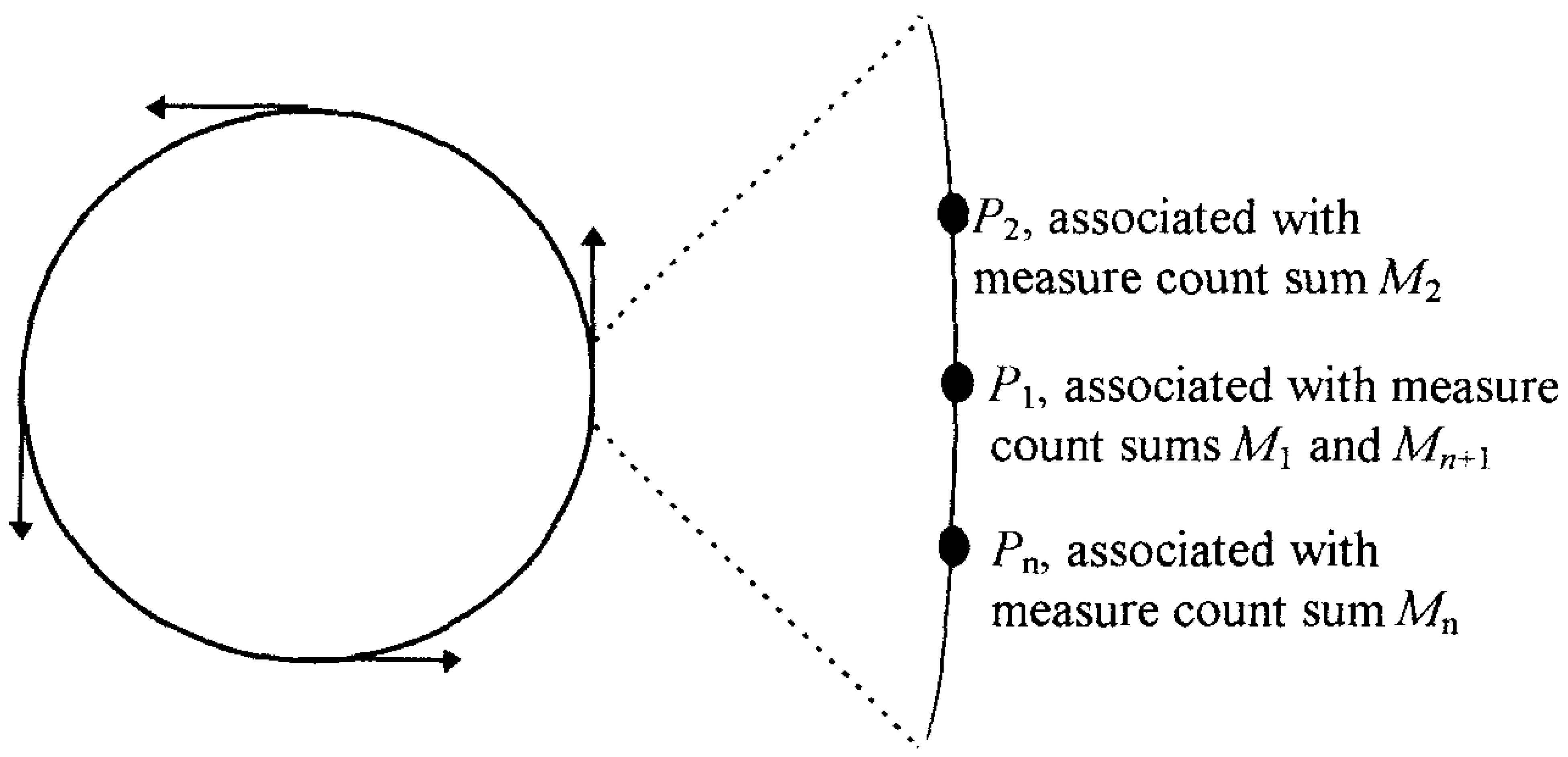

Fig. 7.2 On the left, a closed time-like curve in a Gödelian universe is illustrated. The arrows indicate the temporal orientation of the curve as established at different points by the two slit experiment. On the right, a detail of the curve is illustrated. Three arbitrary points, P_n, P_1 and P_2 are illustrated. The measure count sum associated with each point is indicated. It can be seen that the arbitrary point P_1 is, paradoxically, associated with two different measure count sums.

4 The Causal Theory Of Time Order

Up until now, I have focussed upon interactions deriving from thermodynamics and quantum mechanics in establishing the direction of time around a closed time-like curve in order to show that such curves do not appear to be compatible with the behaviour of thermodynamical and quantum mechanical systems in our universe, possibly implying that universes containing closed time-like curves are not physically possible.

It is however possible to give an account of the direction of time in terms of causality *per se*, rather than in terms of specific physical interactions.

If an account of the direction of time were required in causal terms, it would be possible to assert that a cause always precedes its effect, and that this fact alone is sufficient to establish that time has a direction. However, there are a number of problems with this approach. To begin with, the assumption needs to be made that cause does always precede effect, and it does not appear that this can simply be taken as a given. Furthermore, we need to identify what counts as a cause and what counts as an effect, and both of these activities seem to require a prior notion of temporal ordering. Therefore, an attempt to reduce temporal order to causal order seems to involve installing concepts derived from temporal order into the causal order which is being invoked as the basis of temporal order. Sklar expresses reservations about the possibility of reducing temporal order to causal order on much these grounds.

> "We will discover that ending the restriction of attention to special relativity makes the reduction seem quite a bit less plausible." (Sklar 1974, pp.322-3)

Sklar's comment here is a nod to, amongst others, Reichenbach who couches his causal theory of time order in the context of special relativity.[11]

My comments here are only intended to indicate the possibility of a causal theory of time order, since to do the theory justice would require detailed analysis. My overall strategy remains one of seeking to show that we are not compelled by our current theories of physics to adopt a particular temporal metaphysics.

5 Conclusion

The irreversibility made apparent during measurement of a quantum system provides us with a means of establishing a temporal orientation in a structurally simple universe. Such a universe can be interpreted in terms of an objectively distinguished present metaphysics, since at least one sequence of global time slices is defined within it, namely that sequence along which the measure count sum of the universe increases.

It was shown that, if we assume that one consequence of being time-like is that the measure count sum associated with points along a time-like curve in a particular direction should always increase, then a paradox arises for a closed time-like curve of the type which arises in Gödel's rotating universes. This paradox is similar to the paradox which arises if we assume that the entropy of a closed system associated with points along a closed time-like curve in a particular direction should always increase.

I concluded the chapter by briefly considering whether it is possible to give an account of the direction of time in terms of causal ordering.

[11] Confer Reichenbach 1956.

8

The Past, Present And Future Of Temporal Metaphysics

1 Static Block Universe Theories And Objectively Distinguished Present Theories Of Temporal Metaphysics

Over the preceding chapters I have examined a number of proposed transitions from theories of physics, which embody various concepts of time, to theories of temporal metaphysics. I began in chapter 1 by postulating that there are broadly two types of temporal metaphysics available, a static block universe metaphysics and an objectively distinguished present metaphysics.

A static block universe metaphysics, as we have seen, is one which states that global time slices which are defined as past, present and future moments of time by some arbitrary observer are not existentially distinct, that is, they all exist in exactly the same way. The experience by an inhabitant of such a universe of the passage of time is therefore not a reflection of any underlying existential difference between time slices in that universe, although the experience may be explained in terms of the arrangement of time slices in sequence according to a varying physical property or properties. The experience of one temporal part of an inhabitant of such a universe is an experience of one time slice in a sequence of time slices, and it can be argued that this experience will contain an experience of the passage of time as a consequence of its place in such a sequence.

An objectively distinguished present metaphysics is one which states that global time slices which are defined as past, present and future moments of time relative to some arbitrary observer are objectively distinct. The experience of the passage of time by an inhabitant of a universe which is correctly described in terms of an objectively distinguished present theory therefore reflects the physical conditions which obtain in that universe, and hence the distinction drawn by such an inhabitant between past, present and future moments of time reflects an underlying physical distinction between global time slices in the universe.

As we have seen, objectively distinguished present theories of temporal metaphysics can be subdivided according to whether the distinction between moments of time is taken to be correlated to a difference in the existential status of global time slices, or to a difference in the state of determinacy of global time slices. Those theorists who conceive of the distinction between moments of time being correlated to the existential status of global time slices are either presentists or growing block universe theorists. Those theorists who conceive of the distinction between moments of time being correlated to the state of determinacy of global time slices I have termed growing determinacy universe theorists. Growing determinacy universe theorists regard the existential status of global time slices as invariant, whilst claiming that their physical status can vary in terms of their state of determinacy.

I noted that the distinction between presentist and growing block universe theories rests upon the envisaged status of past global time slices. For a presentist, only the present global time slice is deemed to exist. Past global time slices, like future global time slices, are deemed not to exist. For a growing block universe theorist, the present global time slice is the time slice which is coming into existence, but global time slices are envisaged as not going out of existence once they have come into existence, so that existing time slices other than the present time slice constitute past time slices. Global time slices are therefore cumulative in a growing block universe.

2 Four Theories Of Physics

In chapters 2 through to 7, I considered four of the most important branches of modern physics, special relativity, general relativity, thermodynamics, and quantum mechanics, to ascertain whether the theories associated with each branch of physics appear to imply either a static block universe or an objectively distinguished present temporal metaphysics as the temporal metaphysics of our universe.

(a) Special Relativity

In chapter 2, I considered Putnam's argument for a static block universe metaphysics on the basis of special relativity. According to special relativity, observers moving at different velocities relative to one another define different simultaneity hyperplanes[1] as their respective present moments. Consequently, a state of affairs which lies in my future may lie in the present of another observer moving relative to me. If I assume that a present state of affairs is a state of affairs which exists, then I can conclude that a state of affairs which is in my future exists, since it is present relative to another observer. On this basis, Putnam argues that past and future states of affairs, defined relative to some arbitrary observer, exist in exactly the same way as present states of affairs. This conclusion implies that there is no difference in the existential status of past, present and future states of affairs defined relative to some observer. It further implies that a static block universe is a universe in which all moments of time are determinate, since if a state of affairs in my future exists, then I cannot bring it about that that state of affairs does not exist when I experience that state of affairs in my present..

I observed that Putnam's argument is based upon a number of metaphysical assumptions. Putnam assumes a reality relation, to the effect that if *I*-now am simultaneous with a thing (or a state of affairs), that thing (or state of affairs) is real. This reality relation appears to be a basic premise of presentism. Therefore, a presentist who wishes to challenge Putnam's choice of reality relation will have to adopt a different reality relation. We saw that other reality relations have been suggested, such as the reality relation proposed by Stein, but noted some of the problems which arise for anyone adopting a reality relation other than the one adopted by Putnam.

Putnam accepts the definition of simultaneity employed within special relativity, even though this definition is itself a convention which incorporates metaphysical assumptions. I therefore considered whether other ways of defining simultaneity might be possible, at least in principle, but concluded that no other ways are currently available in practice.

I noted that an argument for a static block universe temporal metaphysics based on special relativity was rejected by Gödel, some eighteen years before Putnam proposed his similar argument, on the grounds that special relativity strictly only applies to universes which do not contain matter, and therefore does not strictly apply to the universe which we inhabit.[2]

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[1] Simultaneity hyperplanes are a subset of global time slices. They are definable in universes modelled on the basis of special relativity, but have no invariant meaning in universes modelled on the basis of general relativity.

[2] Special relativity can provide a good approximate description of the behaviour of systems in our universe, provided that the distances and masses involved in a system are not too large. Special relativity is not therefore suitable for describing the behaviour of our universe as a whole.

I concluded therefore that any argument for a static block universe temporal metaphysics on the basis of special relativity needs to be seen as embodying metaphysical assumptions already implicit in special relativity. Such an argument has limited use unless it is considered in the context of an appraisal of the temporal metaphysics implied by other theories of physics.

(b) General Relativity

In chapter 3, I considered Gödel's argument for a static block universe temporal metaphysics on the basis of general relativity.

I began by considering Gödel's concept of existential change, the type of change which he assumes must occur in a universe if that universe is to be appropriately described in physically distinguished present terms. Gödel suggests that the only coherent account one can give of a physically distinguished present theory is an account in which moments of time are described as passing into and out of existence. He only appeared to consider presentism therefore.

I then proceeded to examine Gödel's argument against presentism. As we observed, Gödel had modelled some universes on the basis of Einstein's field equations, the equations which constitute the mathematical foundations of general relativity, such that the model universes contain space-time structures called closed time-like curves. These curves are distributed in such a way throughout the space-time of Gödelian universes that it is not possible to foliate a Gödelian universe by a sequence of global time slices and therefore it is not possible to give an objectively distinguished present account of such universes. Consequently, they can only be described in static block universe terms.

Although Gödel's argument is specifically aimed against presentism, I noted that both a growing block universe theorist and a growing determinacy theorist need to be able to define a sequence of global time slices in a universe, so that if it is impossible to define such a sequence in a Gödelian universe, no objectively distinguished present account of such a universe can be given.

I concluded chapter 3 by noting that an advocate of an objectively distinguished present metaphysics is entitled to point out that there may be physical criteria, deducible perhaps from other theories of physics, which rule out Gödelian universes as physically possible.

(c) The Modal Step

In chapter 4, I examined Savitt's analysis of Gödel's argument. Savitt points out that, if our universe is not a Gödelian universe (Gödel nowhere claims that it is), then Gödel is only entitled to conclude that our universe cannot be described in terms of an objectively distinguished present temporal metaphysics, on the basis of his observation that a Gödelian universe cannot be described in terms of an objectively distinguished present temporal metaphysics, if he can justify taking what Savitt terms a modal step.

Gödel needs to motivate the transition from the observation that some universes which conform to Einstein's field equations are not describable in objectively distinguished present terms, to the claim that all universes which conform to Einstein's field equations, including our own, are not describable in objectively distinguished present terms.

I suggested that this modal step may be difficult to motivate. It rests on the assumption that the temporal metaphysics of a physically possible universe is necessarily the temporal metaphysics of all physically possible universes. I indicated that this assumption can at least be called into question.

Since Gödel is not claiming that our universe is a Gödelian universe, he can also be understood as assuming that it is conformity to Einstein's field equations which dictates the temporal metaphysics of a universe, rather than the existence of spacetime structures such as closed time-like curves within that universe. For Gödel, closed time-like curves appear to be evidence that the appropriate temporal metaphysics for universes which conform to Einstein's field equations is a static block universe metaphysics, but it is conformity to the field equations themselves which is the reason why non-Gödelian universes can only be described in static block universe terms.

Given that Gödel himself refers to universes which conform to Einstein's field equations but which are not Gödelian universes as universes which can be described in objectively distinguished present terms, his assumption that all universes which conform to Einstein's field equations are in fact static block universes appears to be unjustified, but seems to derive from the particular way in which he interprets the field equations as laws of nature.

Savitt's analysis of Gödel's argument is of assistance to any theorist who wishes to maintain that an objectively distinguished present theory is a possible account of the temporal metaphysics of our universe, whether that theorist is proposing a presentist, growing block universe or growing determinacy theory.

(d) Thermodynamics

In chapter 5, I examined Einstein's response to universes modelled by Gödel. Einstein points out that general relativity does not appear to imply a temporal orientation for time-like curves of any kind, whether closed or open, but suggests that it might be possible to establish a temporal orientation by recourse to thermodynamical considerations.

Einstein observes that a point from which a signal is sent on a time-like curve must be located at an earlier moment of time than the point on the same time-like curve at which the signal is received. We can deduce that the point from which the signal is sent is at an earlier moment than the point at which the signal is received because the sending of a signal increases entropy, and the second law of thermodynamics implies that for any two moments of time, the entropy associated with the later moment will always be higher than (or the same as) the entropy associated with the earlier moment. The entropy associated with the later moment will never be lower than the entropy associated with the earlier moment, according to the second law of thermodynamics.

The sending of a signal therefore allows us to establish the temporal orientation of a time-like curve. I indicated that when we apply Einstein's signalling technique to a closed time-like curve of the type which occurs in a Gödelian universe, a paradox arises. If we assume that the same temporal orientation is maintained all the way around the closed time-like curve, then we find that we can demonstrate for any arbitrary point on the closed time-like curve that the point is associated with at least two different entropies. I considered whether we should therefore deny the physical possibility of universes containing closed time-like curves, on the grounds that they cannot conform to the second law of thermodynamics.

By identifying as a privileged sequence of global time slices that sequence of time slices along which the entropy of a universe as a whole consistently increases, it is possible to establish a privileged sequence of time slices in a universe which conforms to the second law of thermodynamics. Such a universe is therefore compatible with an objectively distinguished present temporal metaphysics.

I noted that although the second law of thermodynamics may enable us to identify a privileged sequence of global time slices in a universe, it does not suggest that one of the hyperplanes in this sequence is physically distinct from any of the other hyperplanes in the sequence. It does not therefore imply an objectively distinguished present theory in preference to a static block universe theory. I concluded therefore that whilst a universe which conforms to the second law of thermodynamics is compatible with an objectively distinguished present metaphysics, thermodynamics does not imply that either a static block universe or an objectively distinguished present temporal account is the correct account of the temporal metaphysics of such a universe.

(e) Quantum Mechanics

In chapter 6, I considered various interpretations of quantum mechanics, before going on to consider whether performing a measurement on a quantum system brings about an irreversible change in the evolution of that system. I indicated that the observed irreversibility of measurement of quantum systems may be interpreted as a reflection of the direction of time in the universe as a whole, rather than an irreversibility intrinsic to quantum mechanical systems.

In chapter 7, I considered a universe in which quantum measurement either brings about or serves to indicate irreversible change, and noted that it is possible to define a privileged sequence of global time slices in such a universe. The privileged sequence of time slices in such a universe is the sequence along which the changes brought about by measurements of quantum systems are irreversible. Such a universe is therefore compatible in principle with an objectively distinguished present temporal metaphysics.

I went on to observe that if measurement of a quantum system can be used to indicate the direction of time in a universe, then we can use such measurement to establish a temporal orientation on a time-like curve in much the same way as we can use Einstein's signalling technique.

I demonstrated that if we perform measurements on quantum systems around a closed time-like curve of the type found in Gödelian universes, in order to establish the temporal orientation of the closed time-like curve, then a paradox arises similar to the paradox which arises when we apply Einstein's signalling technique around such a closed time-like curve. The paradox was observed to arise if we assume that the same temporal orientation can be defined all the way around the closed time-like curve.

I concluded the chapter by briefly considering whether it is possible to explain the direction of time in terms of a causal theory.

3 An Overview Of The Analysis

I began by examining proposed transitions from the special and general theories of relativity to temporal metaphysics, proposed transitions which interpret both theories of relativity as implying a static block universe metaphysics. I indicated that the proponents of these arguments based on relativity tend to conceive of objectively distinguished present theories as implying that the physical difference between global time slices, as reflected in the description of moments of time as past, present or future, must consist in the existential status of those time slices. The concept of a objectively distinguished present is commonly interpreted, both by its supporters and its opponents, as implying a presentist metaphysics in which future moments of time do not exist, the present moment of time does exist, and past moments of time do not exist. Some theorists, termed growing block universe theorists, envisage past moments of time existing in addition to the present moment of time.

Inspired in part by Aristotle's account of temporal metaphysics, I went on to consider whether the distinction between global time slices which is reflected in the description of moments of time as past, present and future could consist in the state of determinacy of those moments, rather than their existential status. Thus I considered whether we might equate future moments of time with indeterminate global time slices, past moments of time with determinate global time slices, and the present moment of time with that global time slice which is becoming determinate.

Couching an objectively distinguished present theory in terms of determinacy allows one to describe a *block* universe, a universe in which a complete sequence of global time slices is defined, in terms of a growing determinacy metaphysics. Although all the global time slices in the block universe are posited to exist, the fact that the sequence of time slices is in transition from indeterminacy to determinacy implies that the experience by an inhabitant of such a universe of the passage of time reflects an actual physical difference between time slices in that universe.

Although the concept of determinacy allows one to describe a potential objective correlate of the experience of the passage of time by an inhabitant of a block universe, the implied temporal metaphysics is that of a growing determinacy universe rather than that of a static block universe, since it relies upon a distinction in the state of determinacy of moments of time, and it is precisely such a distinction which static block universe theories deny.

4 Physics, Metaphysics, And Model Universes

At no point have I claimed in the preceding chapters that an objectively distinguished present temporal metaphysics, either expressed in terms of existential status or in terms of determinacy, provides us with the correct description of the temporal metaphysics of our universe. The arguments I have considered have rather been designed to show that the theories of physics which we currently possess, although they do indeed embody concepts of time, do not conclusively imply either that a static block universe temporal metaphysics or that an objectively distinguished present temporal metaphysics is the metaphysics of the universe we inhabit.

The process of modelling a universe on the basis of a theory of physics in order to justify a particular metaphysical claim was observed to raise some important issues. Gödel interpreted the fact that he was able to model universes on the basis of Einstein's field equations such that these universes could not be foliated by a sequence of global time slices as evidence that any universe which conformed to Einstein's field equations, any physically possible universe, should be described in terms of a static block universe metaphysics rather than an objectively distinguished present metaphysics.

I have sought to demonstrate, in response to Gödel's interpretation, that possible universes, universes which are modelled on the basis of one or more of the laws of nature to which our universe conforms, although they may imply a particular metaphysics for themselves, do not unambiguously imply that the same metaphysics is the appropriate description of our own universe.

It might be considered that the more closely a possible universe resembles our universe in terms of the laws of the nature to which it conforms, the more likely it is that a temporal metaphysics which constitutes an appropriate description of that possible universe would constitute an appropriate description of our universe.

5 The Future Of Theory

We can observe that metaphysical issues tend to arise where there are two or more ways of interpreting the available empirical evidence. The development of the theory of relativity in the early years of the twentieth century was perceived by some theorists, both physicists and philosophers, as allowing them to interpret the physical evidence to which the theory of relativity related as evidence for static block universe theories of temporal metaphysics in preference to objectively distinguished present theories of temporal metaphysics. We have seen that one is only entitled to interpret the theory of relativity as supporting static block universe theories if one selectively ignores the metaphysical assumptions which are built in to the theory of relativity, and if one does not take account of other theories of physics which by no means categorically imply static block universe theories.

As new theories of physics become available, it will be necessary to assess whether they unambiguously imply either static block universe or objectively distinguished present theories of temporal metaphysics. It is to be hoped that some of the considerations which have been examined in the preceding pages will assist philosophers in making these types of assessment.

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